PB81-218323

Pilot-Scale Anaerobic Filter Treatment of Heat Treatment Liquor

(U.S.) Hydroscience, Inc.
Westwood, NJ

Prepared for

Municipal Environmental Research Lab.
Cincinnati, OH

Jul 81

U.S. Department of Commerce
National Technical Information Service
NTIS

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA-600/2-81-114	ORD Report	PB81 218323

4. TITLE AND SUBTITLE	5. REPORT DATE
PILOT-SCALE ANAEROBIC FILTER TREATMENT OF HEAT TREATMENT LIQUOR	July 1981
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
Hydroscience, Inc.	
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
Hydroscience, Inc. 363 Old Hook Road Westwood, New Jersey 07675	C36B1C
	11. CONTRACT/GRANT NO.
	Contract No. 68-03-2484
12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
Municipal Environmental Research Laboratory - Cin., OH Office of Research and Development U. S. Environmental Protection Agency Cincinnati, Ohio 45268	Final Nov. 1976-Dec. 1979
	14. SPONSORING AGENCY CODE EPA/600/14

15. SUPPLEMENTARY NOTES
Report written by Eugene Donovan, Jr., Thomas J. Mulligan, James A. Mueller, and Joseph Husband of Hydroscience, Inc., and with the assistance of B. Vincent Salotto, EPA Project Officer. (513)684-7667

16. ABSTRACT

This investigation was undertaken to demonstrate the application of the anaerobic filter in the treatment of liquor waste resulting from heat treatment of raw sludge in municipal sewage treatment plants. The liquor which contains high concentrations of soluble wastes is often returned to the heat end of a plant, where it can impose an additional load on the plant's operation and reduce its efficiency.

Two pilot anaerobic filter columns were operated over a period of 18 months at the Muddy Creek Plant of the Metropolitan Sewer District of Greater Cincinnati. Operational data demonstrated high levels of BOD and COD removals from the raw heat treatment liquor. The generated gas contained 65 to 70 percent methane.

Based on the pilot column studies, a suggested design and costs for an anaerobic filter unit were developed. These costs were compared to costs of other means of treatment such as the aerobic alternative. The anaerobic filter process had lower capital and operating costs than other modes of treatment. The gas produced was calculated to provide fuel to maintain the temperature of the filter at 35 °C, and provide additional capacity for other plant uses. These calculations show a net profit in operating costs. Further investigations to optimize design configurations are suggested.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Sludge, Heat treatment liquor, Disposal of liquor, Anaerobic treatment, Anaerobic filter, Anaerobic digestion, Upflow treatment	Heat treatment liquor, Sludge treatment, Wastewater treatment, Anaerobic treatment, High-strength COD liquor, Wastes from heat treatment of raw sludge	13B

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
RELEASE TO PUBLIC	UNCLASSIFIED	116
	20. SECURITY CLASS *(This page)*	22. PRICE
	UNCLASSIFIED	

EPA Form 2220-1 (9-73)

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE
6 1/2"
9 1/8"
BEGIN LAST LINE OF TEXT
3/8"
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
EPA-287 (Cin.)
(4-76)

EPA-600/2-81-114
July 1981

PB81-218323

PILOT-SCALE ANAEROBIC FILTER TREATMENT OF HEAT TREATMENT LIQUOR

by

Hydroscience, Inc.
Westwood, New Jersey 07675

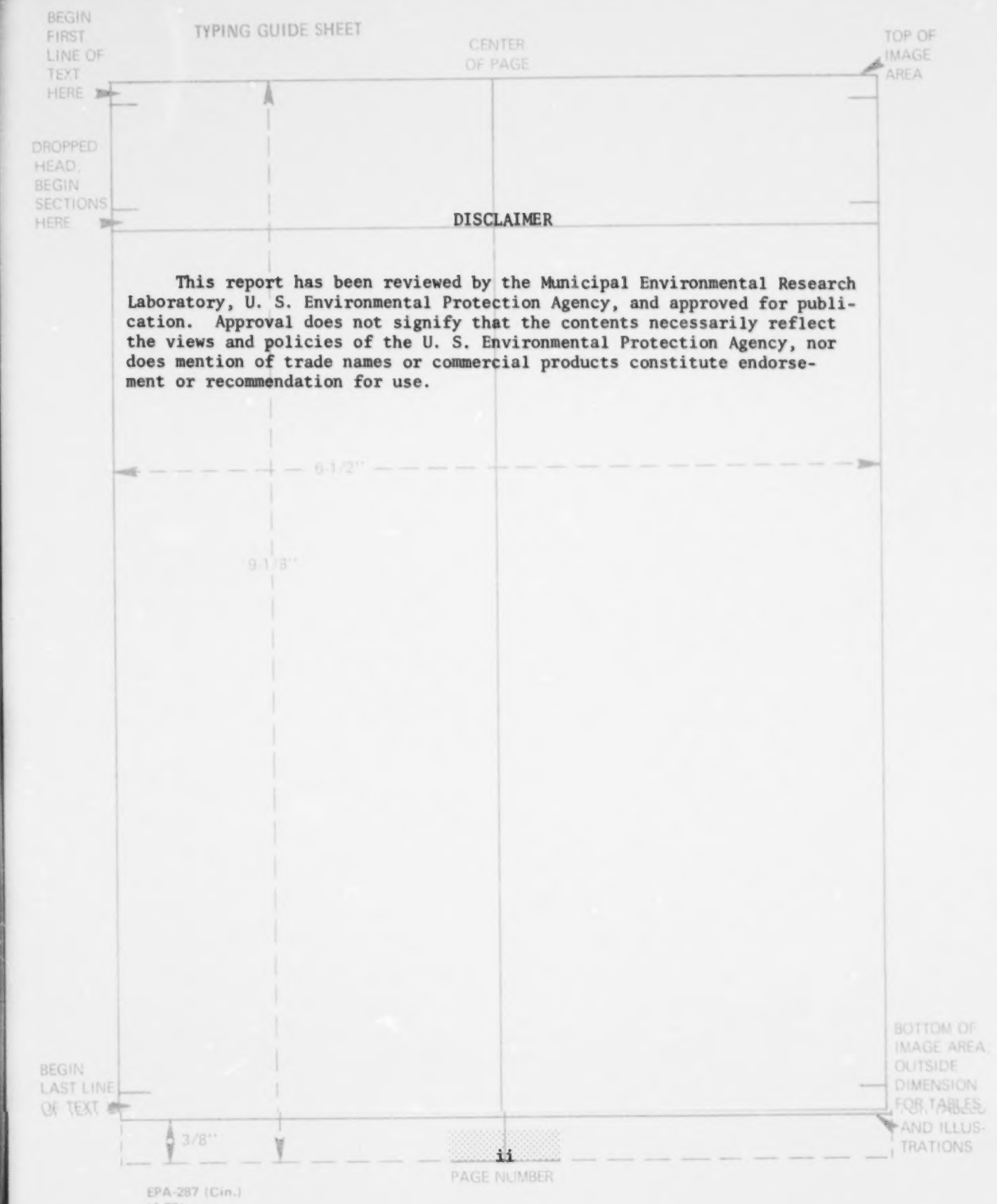
Contract No. 68-03-2484

Project Officer

B. Vincent Salotto
Wastewater Research Division
Municipal Environmental Research Laboratory
Cincinnati, Ohio 45268

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U. S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA 22161



DISCLAIMER

This report has been reviewed by the Municipal Environmental Research Laboratory, U. S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U. S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effect of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

Heat treatment of raw sludge has its advantages, but it produces a waste product that needs further treatment. This report describes the anaerobic filter method as one process that can be used for the treatment of heat treatment liquor.

Francis T. Mayo, Director
Municipal Environemntal Research
Laboratory

TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD; BEGIN SECTIONS HERE
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
1 1/2" 3/8" 1"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

ABSTRACT

This investigation was undertaken to demonstrate the application of anaerobic filter treatment of high-strength liquor resulting from the heat treatment of sludge in municipal sewage treatment plants. This liquor is often returned to the head end of the plant, where it can impose a severe stress on the plant's operation and reduce its efficiency. The anaerobic filter appears to be an acceptable, cost-effective, and energy conserving treatment method for heat treatment liquor before it is returned to the plant.

Two pilot plants were operated over a period of 18 months at the Muddy Creek Plant of the Metropolitan Sewer District of Greater Cincinnati. The pilot plants demonstrated high levels of BOD and COD removal from heat treatment liquor. Gas generated contained 65% to 70% methane. Based on the pilot studies, a suggested design and costs for an anaerobic filter were developed and compared to aerobic treatment alternatives. The anaerobic filter process had lower capital and operating costs than the aerobic alternatives. The gas produced was sufficient to maintain filter operating temperature of 35°C and to provide gas for other plant uses, resulting in a net profit in operating costs.

Further investigations to optimize design configurations are suggested.

This report was submitted in fulfillment of Contract No. 68-03-2484 by Hydroscience, Inc. under the sponsorship of the U. S. Environmental Protection Agency. This report covers the period November 1976 to December 1979, and work was completed October 1979.

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE

CONTENTS

Foreword iii
Abstract iv
Figures vi
Tables viii
Abbreviations and Symbols x
Acknowledgment xi

1. Introduction 1
   - Purpose of Study 1
   - Muddy Creek Treatment Facility 2
   - Background Literature Review 6
2. Summary 13
3. Conclusion 16
4. Recommendations 17
5. Pilot Plant and Experimental Program 18
   - Anaerobic Filters - Pilot Units 18
   - Laboratory Anaerobic Bench Digestors 24
   - Laboratory Anaerobic Filter 28
6. Anaerobic Filter Pilot Plant Results 30
   - Pilot Plant Operation - Phase I 30
   - Pilot Plant Operation - Phase II 41
   - Special Studies 58
   - Laboratory Anaerobic Filter - Results 70
   - Removal Kinetics and Selection of Design Parameters . 79
   - Aerobic Pilot Studies 84
7. Anaerobic Filter Design and Cost Estimates 90
   - Introduction 90
   - Anaerobic Filter Design 90
   - Aerobic Systems Design 96
   - Cost Comparison 96

References 101

BEGIN LAST LINE OF TEXT
3/8"
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

EPA-287 (Cin.)
(4-76)

FIGURES

Number		Page
1	Plant Layout of Muddy Creek S.T.P.	3
2	Heat Treatment System - Schematic	5
3	Anaerobic Filter Pilot Units - Schematic	19
4	Pilot Anaerobic Filters	20
5	Aerobic Pilot Units - Schematic	26
6	Phase I Chronological Plot	32
7	Depth Study - August 10, 1977	37
8	Recirculation Study - Column No. 1	39
9	Dye Concentration Versus Time	42
10	Tracer Study - October 30, 1977	43
11	Phase II - Chronological Plot	46
12	Gas Production Versus COD Loading	48
13	BOD and COD Removal	52
14	BOD Removal Versus Loading Rate and Detention Time	53
15	COD Removal Versus Loading Rate and Detention Time	54
16	Gas Production Versus Soluble COD Removed	56
17	Gas Composition Versus Soluble COD Removed	57
18	Phase II - COD Versus BOD	59
19	Long-Term BOD Tests	61
20	COD of Suspended Solids	62
21	Tracer Study - May 31-June 8, 1978	63

FIGURES (Continued)

Number		Page
22	Depth Study - Column No. 1 Phase II	67
23	Depth Study - Column No. 2 Phase II	68
24	Anaerobic Filter Laboratory Units Chronological Plots	72
25	Laboratory Anaerobic Filter BOD and COD Removal	75
26	Laboratory Anaerobic Filter COD Removal Versus Loading Rate and Detention Time	76
27	Laboratory Batch Digestors - Chronological Plot	78
28	Soluble Effluent BOD-COD Relationship Laboratory Digestor Study	80
29	COD Removal Rate	83
30	Aerobic Pilot Unit Oxygen Utilization	88
31	Schematic Anaerobic Filter System	93

TABLES

Number		Page
1	Average Influent and Effluent Characteristics Muddy Creek Sewage Treatment Plant	2
2	Characteristics of Muddy Creek STP Heat Treatment Liquor Supernatent	6
3	Characteristics of Columbus Jackson Pike STP Heat Treatment Liquor Supernatent	6
4	Summary of Anaerobic Filter Investigations	9
5	Actual Experimental Schedule-Phase I	22
6	Anaerobic Filter Study Schedule Phase-II	23
7	Analytical Schedule Anaerobic Pilot Filters	25
8	Aerobic Experimental Program	24
9	Sampling Schedule - Aerobic Pilot Units	27
10	Laboratory Anaerobic Batch Digestors Analytical Schedule	28
11	Laboratory Anaerobic Filter Program	29
12	Laboratory Anaerobic Filter Sample and Analytical Schedule	29
13	Analyses of Seed Sludge for the Anaerobic Filters	31
14	Phase I - August Operation Summary	35
15	Depth Study on 8/10/77	36
16	Results of Recirculation of Effluent Column 1	38
17	Analyses of Seed Sludge for the Anaerobic Filters	44
18	Column #1 - Phase II 10 Day Average Operation	49
19	Column #2 - Phase II 10 Day Average Operation	50
20	Gas Composition	55

TABLES (Continued)

Number		Page
21	Long-Term Carbonaceous BOD on Heat Treatment Liquor	60
22	Hydraulic Tracer Study Performed 5/31-6/8/78	58
23	Tap Study Results 6/20/78, 7/17/78	65
24	Tap Study Results 8/31/78, 9/13/78	66
25	Filter Attached and Suspended Solids Data	69
26	Laboratory Anaerobic Filter Operation Summary	74
27	Laboratory Filter-Solids	73
28	Laboratory Mixed Anaerobic Digestors Summary of Operation	81
29	Effect of HTL on Activated Sludge Muddy Creek Plant	85
30	Performance Summary Unit 1 and Unit 2	87
31	Design Basis	91
32	Alternative Design Options	94
33	Anaerobic Filter Cost Estimate	98
34	Incremental Cost Estimate for Aerobic Treatment	99
35	Separate Aerobic Treatment Cost Estimate	100

TYPING GUIDE SHEET

ABBREVIATIONS AND SYMBOLS

BOD	-	Biological oxygen demand
Cal	-	Calories
cm	-	Centimeters
COD	-	Chemical oxygen demand
Cu. Ft.	-	Cubic feet
°C	-	Centigrade
d	-	Day
det.	-	Detention
Eff.	-	Efficiency
ft^3	-	Cubic feet
g	-	Grams
hr.	-	Hour
HTL	-	Heat treatment liquor
Ind.	-	Industrial
kg	-	Kilogram
kw	-	Kilowatt
l	-	Liter
lb	-	Pound
m	-	Meter
mg	-	Milligram
min	-	Minute
MLSS	-	Mixed liquor suspended solids
MLVSS	-	Mixed liquor volatile suspended solids
NH_3-N	-	Ammonia-nitrogen
SS	-	Suspended solids
STP	-	Sewage treatment plant
T	-	Temperature
TKN	-	Total Kjeldahl nitrogen
TOC	-	Total organic demand (carbon)
TOD	-	Total oxygen demand
TS	-	Total solids
TVS	-	Total volatile solids
VA	-	Volatile acids
VSS	-	Volatile suspended solids
wk	-	Week

Symbols			Subscript		
%	-	Percentage	t	-	Total
E	-	Void ratio	f(s)	-	Soluble
∅	-	Pound	r	-	Removed

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE

ACKNOWLEDGEMENTS

These studies were conducted at the Muddy Creek Sewage Treatment Plant of the Metropolitan Sewer District of Greater Cincinnati. Mr. Richard A. Vanderhoof, director. The assistance of Mr. Arthur Schwer, assistant director, and Mr. Charles Weider, superintendent of the Muddy Creek Plant, are appreciated. Hydroscience personnel conducting this project included Eugene J. Donovan, Jr., project manager; Thomas J. Mulligan and Dr. James A. Mueller, technical reviewers; and Joseph Husband, Stanly Kmietz, Timothy Sullivan, David Pitts, Terry Schomer, and Francisco Cardona, the engineers and technical specialists who operated the pilot plant and assisted in data analyses and report preparation. The assistance of the EPA Project Officer, B. Vincent Salotto, is also appreciated.

9-1/8"
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

EPA-287 (Cin.)
(4-76)

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE

SECTION 1

INTRODUCTION

PURPOSE OF STUDY

At present, there are approximately one hundred waste treatment plants in the United States which use heat treatment systems or have such systems under construction. The oxygen demand to the main plant from these systems is as much as 30% of the raw domestic sewage load, and may seriously hamper the treatment plant from meeting the increasingly stringent effluent discharge requirements.

The purpose of this project was to demonstrate on a pilot-scale basis the feasibility of anaerobic filter treatment of return liquors from thermal sludge conditioning at a municipal sewage treatment plant. The pilot plant was operated under various conditions to obtain design parameters for sizing a full-scale unit. The study included an evaluation of the effect of untreated return sludge heat treatment liquor and anaerobically treated liquor on the performance of the activated sludge process using pilot-scale systems. Cost comparisons between aerobic treatment alternatives of these liquors and the anaerobic filter were made.

Heat Treatment of Sludge

During the past fifteen years, many municipal waste treatment plants have constructed heat treatment or wet-air oxidation processes as a part of their sludge disposal systems. The wet-air oxidation process is a method of incineration which uses the principle of wet combustion to degrade the organic matter in sludges. Those solids that remain are more easily dewatered by filtration or settling. Basically, the process is chemical oxidation (under pressure and at elevated temperatures) of combustible material in water. Atmospheric oxygen is the oxidant, and the organic matter of sewage sludge is the combustible material. Oxidation typically takes place at 177°-205°C, and at 585-1463 kg/cm^2 pressure.

It is apparent that during wet-air oxidation, the complex molecules which make up the organic portion of the sludge are broken down to their simpler, usually soluble, constituents. The liquor obtained by decanting or dewatering low pressure oxidized sludges contains suspended solids and simple and complex dissolved organics which exert BOD and COD. The liquor is composed of the same basic classes of organic compounds as are found in sewage sludges, such as protein, lipids, total sugars, starch, and crude fiber.

BEGIN LAST LINE OF TEXT HERE
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

EPA-287 (Cin.) (4-76)

The Porteous system of thermal sludge conditioning raises the temperature and pressure of the sludge to a range of 177°C to 188°C and 512 kg/cm^2 to 644 kg/cm^2 in the reactor. The sludge is pumped into a reactor by high pressure pumps and the sludge is heated by heat exchangers. The heat and pressure cause water to be released from the cell structures of the solids which enables the sludge to be dewatered easily by means of vacuum filtration or centrifuging, without the use of chemical coagulating agents. Unlike the wet-oxidation method, there is no oxygen and therefore no reduction of the total mass but portions of the solids will be solubilized and thus reduce the total dry solids in the reactor effluent. The resulting liquors are similar to those from wet air oxidation processes.

In the past, two methods have been used to treat the resultant liquor. Either the liquors were recycled to the head end of the conventional activated sludge system, or a separate aerobic treatment system was constructed to treat the liquor, prior to discharge into the treatment plant flow. The cost of treating these return liquors is significant.

A recent study conducted at a wastewater treatment plant in Colorado Springs, Colorado,[27] which has a heat treatment system, showed that the recycle liquor (which is returned to the biological treatment system) contributes 21% of the total BOD load to the system and 30% of the total suspended solids.

MUDDY CREEK TREATMENT FACILITY

The pilot plant study project was conducted at the Muddy Creek Wastewater Treatment Plant, operated by the Metropolitan Sewer District of Greater Cincinnati. The plant is located on the Ohio River 16 kilometers downstream from downtown Cincinnati. This is a well operated secondary wastewater treatment plant, treating predominently domestic sewage from a combined sewerage system. A layout of the treatment plant is shown in Figure 1, taken from the plant operational manual prepared by Grant, Brundage, Baker and Stauffer, Ltd. The Muddy Creek Treatment Plant was expanded to a fifty six thousand eight hundred cubic meters per day secondary treatment facility in 1973. The expansion was designed to meet population growth expected in the year 2000, and to produce an effluent containing not more than 10 mg/l of biochemical oxygen demand (BOD) and 12 mg/l of suspended solids (SS). Typical influent and effluent characteristics for the treatment plant in 1977-78 are presented in Table 1. The heat treatment process was not in operation.

TABLE 1. AVERAGE INFLUENT AND EFFLUENT CHARACTERISTICS
MUDDY CREEK SEWAGE TREATMENT PLANT (Cincinnati, Ohio)

Parameter		Design	Actual - 1977-1978 Influent	Effluent	% Reduction
Flow m^3/d		56,800	27,250	-	-
BOD_5	mg/1	200	67	4	94
	kg/d	12,800	1,830	109	-
SS	mg/1	225	130	10	92
	kg/d	12,800	3,550	270	-

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE

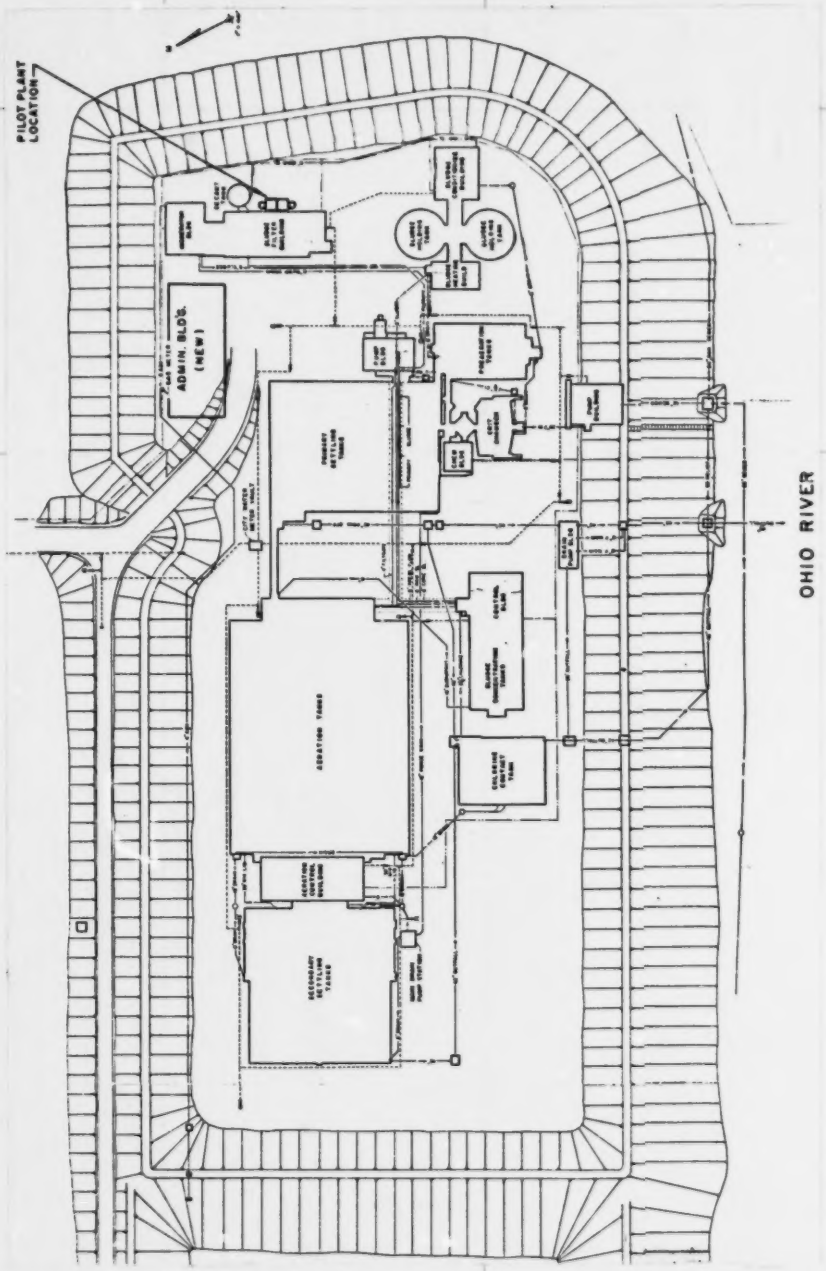


Figure 1. plant layout of Muddy Creek S.T.P.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

EPA-287 (Cin.)
(4-76)

Sludge Handling Facilities

The Muddy Creek plant sludge handling facilities are designed to handle 22,700 kgs. per day. Figure 2 from the operation manual, is a schematic of the sludge handling system. Primary and secondary sludges from the clarifiers are thickened in an air flotation system. The thickened sludge is pumped to a holding tank from which the sludge is pumped to the thermal sludge conditioning system.

The thermal reactor is an insulated pressure vessel designed to hold the sludge for approximately forty-five minutes at a flow rate of 15.1 cubic meters per hour, at a pressure of 805 kg/cm^2 psig, and a temperature of 177°C to 188°C. The pressure in the reactor forces the sludge out of four ports in the bottom of the reactor through the "hot" section of the sludge heat exchanger to the decant tank.

The decant tank receives the thermally conditioned sludge and the gases released from the reactor. Here the sludge is thickened and the gases are deodorized in a gas fired after-burner located on top of the decant tank. The thickened sludge is pumped to the vacuum filters. The heat treatment liquor decanted from the sludge and vacuum filter filtrate is recycled, either to the sludge flotation units or the aeration tanks.

Sludge discharged from the vacuum filters is incinerated. The multi-hearth incinerator ash is discharged into a water-filled tank, and the slurry is pumped to a diked lagoon, located at the west side of the treatment plant site.

Heat Treatment Liquor Characteristics

The heat treatment system was designed to operate at full plant capacity, sixteen hours per day, five days per week. Since plant startup, operating periods have been infrequent because of mechanical difficulties.

Samples of the heat treatment liquor supernatant were collected over a one-month period in April and May 1975, from the decant tank receiving the heat treatment sludge. The sludge feed to the heat treatment unit was a mixture of raw, primary and waste activated sludges. Table 2 shows the reported characteristics for Muddy Creek from April to May, 1975 and Table 3 shows typical heat treatment liquor characteristics of the Jackson Pike STP, Columbus, Ohio, which was used for portions of the study.

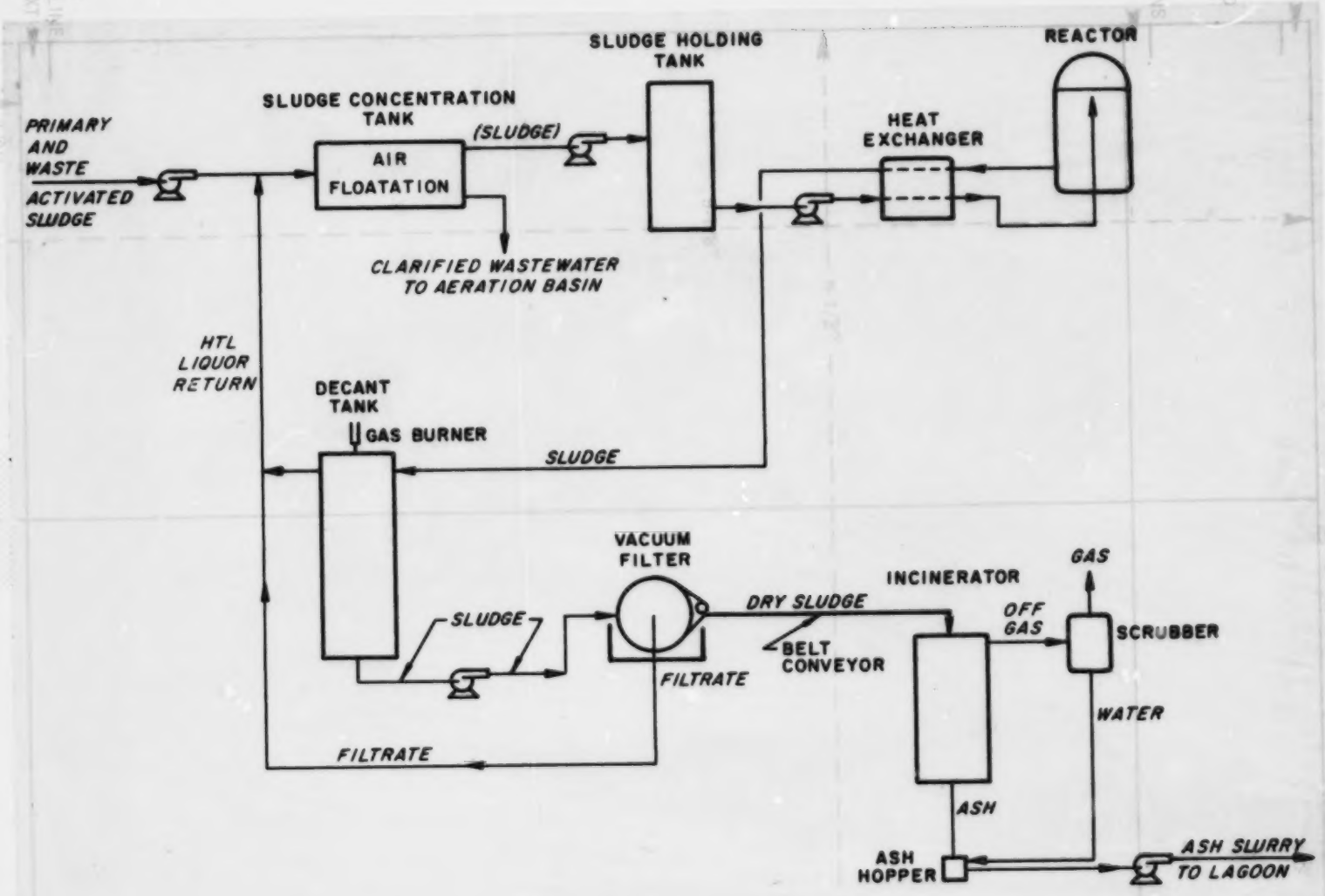


Figure 2. Heat treatment system – schematic.

TABLE 2. CHARACTERISTICS OF MUDDY CREEK SEWAGE TREATMENT PLANT (CINCINNATI, OHIO) HEAT TREATMENT LIQUOR SUPERNATANT (FEED) April - May, 1975

Constituent	Range	Average
pH, unit	5.4 - 6.1	5.6
Alkalinity, mg/l	400 - 820	680
Total Solids, mg/l	3,720 - 6,310	5,860
Volatile Solids % of TS	79.8 - 85.0	82
COD, mg/l	3,050 - 8,850	6,190
BOD, mg/l	1,080 - 4,150	2,610
TKN, mg/l	355 - 720	510
NH_3-N, mg/l	133 - 280	180
TOC, mg/l	1,725 - 3,200	2,450
Volatile Acids, mg/l	117 - 1,700	1,270

TABLE 3. CHARACTERISTICS OF COLUMBUS JACKSON PIKE SEWAGE TREATMENT PLANT (OHIO) HEAT TREATMENT LIQUOR SUPERNATANT April - August, 1978

Constituent	Range	Average
pH, unit	4.9-5.8	5.2
Alkalinity, mg/l	600-1560	1075
Total Solids, mg/l	7390-8460	7735
Volatile Solids %	55-83	71
COD, mg/l	10160-11540	10750
BOD, mg/l	3830-6100	4965
TKN, mg/l	840-990	920
NH_3-N, mg/l	270-390	295
Volatile Acids mg/l	1970-2230	2085

BACKGROUND LITERATURE REVIEW

Anaerobic Filter Treatment

The anaerobic filter is basically a column or tower filled with rock or synthetic media operated in the upflow mode. Biological growth accumulates on the media and in the void spaces, similar to a trickling filter. Higher biological solids concentrations are present than in a conventional anaerobic digester.

The biological reaction occurs in two phases: initially, organic matter is converted to volatile acids plus biological solids followed by conversion to methane and carbon dioxide plus biological solids. With methane and carbon dioxide as the end products, no net oxidation occurs in the reaction, thus no outside electron acceptor such as oxygen is required. The amount of energy liberated in the reaction is relatively low compared to aerobic systems resulting in relatively low solids production.

The anaerobic biological reaction is optimum at approximately 35°C for mesophilic organisms. Both reactions occur somewhat simultaneously, however, some volatile acids buildup occurs in the filter, typically with peak concentrations at the bottom. This buildup tends to drop the pH of the system which must be adequately buffered to maintain the pH in the optimum range for the methane formers, about 6.5-7.5.

Due to the anaerobic filter's capability of removing large amounts of organic matter with no oxygen required, its major application is the pretreatment of high strength wastes. It can remove large quantities of COD at lower cost and produce significantly less solids than aerobic systems. A summary of anaerobic filter investigations conducted to date with their significance is given in Table 4. In 1968, Young and McCarty[1,2] conducted the initial research on the filter, and developed a mathematical model which was useful to describe the various process mechanisms, but too complex for design.

Following Young and McCarty's work, a number of studies were conducted to determine the applicability of the process to various types of industrial waste. Successful operation was obtained for all the wastes studied, except for petrochemical wastes, the latter due either to the toxicity of the raw waste, high H_2S concentrations, or low pH produced in the filter.

The studies by Pailthorp and Richter[9,10] showed the costs of the anaerobic filter to be about one-half those of an aerated lagoon system. Based on this feasibility, a full scale plant was constructed at Spokane, Washington, in January of 1971 as an interim treatment measure for a wheat starch waste. The plant, which remained in operation for fifteen months, yielded about 65% COD removal (76% soluble).

A recent paper by Mueller and Mancini of Hydroscience[25] presented the results of a research effort conducted to obtain a useful kinetic model of the system, and to push the system experimentally to the limits of its capability. The study concluded that the anaerobic filter is a viable system for treatment of high strength and high temperature wastes. It will yield a high degree of organic carbon removal at relatively low operating cost, and low sludge production compared to the aerobic biological systems. The system also produces methane, a potentially usable end product.

A report by Haug, et. al.[26] reported good success with the use of a bench scale anaerobic filter for the treatment of sludge heat treatment liquor. The filter was loaded at a two day detention time and a loading rate of 4.8 kg COD/m^3/d. A COD removal of 76% was reported along with 85% BOD removal.

The use of an anaerobic filter as a means of pretreating the supernatant and filtrate from a heat treatment system, prior to returning the liquid to the plant will benefit the aerobic plant in two ways. First, it will reduce total organic load on the main plant by as much as 20%, or more. Secondly, since most of the heat treatment systems are operated on an intermittent basis, the result is that the total organic load to aerobic treatment abruptly changes at frequent intervals, causing a negative effect on the stability of the biological system, and a decrease in its ability to maintain a consistently low effluent BOD. The anaerobic filter has been demonstrated to be much less sensitive to variations in applied organic loading, thus, the use of such a system to reduce the variability of organic loading to the main plant by pretreating heat treatment return liquor should significantly improve effluent quality.

TABLE 4. SUMMARY OF ANAEROBIC FILTER INVESTIGATIONS

Investigator	Reactor	Waste	COD Loading* #/d-1000 ft^3 (kg/d/m^3)	Detention Time (hr)**	COD Removal Eff. (%)	Significance
Young & McCarty[1,2] 1968	6'x5.5" Col. 1-1 1/2" Stone ε = 0.42 T = 25°C	Volatile Acid & Protein Carbohydrate 375-12000 mg/1 COD	26.5-212 (.42-3.4)	4.5-72	56-98	Ground breaking study, kinetic analysis with math model, simplified design equation
Plummer[5,6] & Malina, 1968	11-16" high Col., Raschig Rings & Berl Saddles ε = 0.65-0.75 T = 35°C	Food Processing (carbohydrate) 8500 mg/1 COD	100-640 (1.6-10.3)	13-83	30-86 (55-86, Soluble)	Inability of shallow filter to capture solids, Effect of sludge age on COD removal
Clark & Speece[7] 1970	3'x5.5" Col. 1-1 1/2" Stone ε = 0.46 T = 33°C	Acetic Acid, 6400 mg/1 COD	370 (5.9)	12	30-80	Described pH inhibition factor optimum removals for filter occur at $6 \leq pH \leq 8$
Pailthorp[8] et al, 1971	4'+8' columns 1 1/2" stone T = 19-22°C	Potato Processing Waste, 3000 mg/1 COD	33-145 (.5-2.3)	13-59	41-79	Ind. Waste Application, Economically comparable to An. Contact & Act. Sludge
Richter, et al, 1971 Taylor[19] 1972 Dorstal[22] 1974	20' high, 30' diameter full scale plant, Spokane, Wash. rock, 1-2" top 2-3" bottom ε = 0.40	Wheat starch waste, SS=370-8360 mg/1 <2300> COD=5930-13, 100 mg/1 <8500>	237 (3.8)	22	65 (76% Soluble COD Removal)	First Full Scale, Anaerobic Filter, Economic & Operational Feasibility, Filter effluent settling + aerobic treatability studies.

TABLE 4 (Continued)

Investigator	Reactor	Waste	COD Loading* #/d-1000 ft^3 (kg/d/m^3)	Detention Time (hr)**	COD Removal Eff. (%)	Significance
Hovious et. al[10], 1972	Lab Scale 25"x35" Col. 1" Berl Saddles ϵ = 0.58 T = 32-35°C	Synthetic Organic- alcohols, aldelydes, acids, amine, glycol, phenol, 2000 mg/l COD, 20000 mg/l COD-system failure	35-130 (.6-2.1)	17-46	64-76	Ind. Waste application Toxicity effect of shock load of conc. organic waste, petrochemical waste inhibitory to methane formers possibly due to high VA=2000 mg/l (pH=?) or high H_2S =
	Pilot scale 6'x1' Cols. 1" gravel ϵ = 0.41 T = 34°C	Petrochemical, 2000-8000 mg/l COD	40-145 (.5-1.9)	72	10-13	50-100 mg/1, Anaerobic Lagoon is system of choice.
Forge, et. al.[11,12], 1972	6'x6" Col, Crushed limestone, ϵ = 0.45 T = 35°C	Brewery Press Liquor, 6000-27,000 mg/l COD	50-400 (.8-6.4)	15-330	30-97	Ind. Waste Application, step feed operation, limestone media reduce chemical required, aerobic treatability of partially stabilized effluent.
Campbell[14] 1973	Ping Pong Balls, T - 20°C	Nonionic Detergent, 2000-6000 mg/l COD	25-75 (.4-1.2)	48	55-83	Ind. Waste Application

TABLE 4 (Continued)

Investigator	Reactor	Waste	COD Loading* #/d-1000 ft³ (kg/d/m³)	Detention Time (hr)**	COD Removal Eff. (%)	Significance
Tadman[13], 1973	5'x3" Col, 1" intalox saddles, ε = 0.8 T = 25&35°C	Peptone-Glucose, Brewery, Paper Mill condensate, Acetic & Glycolic acid, TOC=2500-16100 mg/l	62-450 (Based On TOD) (1.0-7.2)	12-48	73-94 (Based On TOD)	Ind. Waste Application, TKN buffering capacity, Temp. Effect-10% drop in efficiency for 10°C drop in temperature, heat value of gas = 10°C/4500 mg/l TOD. Intermittant operation (5 days on/2 days off) beneficial
El-Shafie & Bloodgood[15], 1973	6 filters in series-each 15"x5.5" 1-1.5" gravel, T = 30°C	"Metrecal", 11000 mg/l COD	427 (6.8)	18	70-95	Branched chain acid degrade slower than straight. Total N remains constant in system. System possibly effected by low pH toxicity.
Dennis & Jennett[16,23] 1974, 1975	3'x5.5" Col, 1-1.5" stone, ε = 0.47 T = 37°C	Pharmaceutical waste (~95% methanol), 1250-16000 mg/l COD	14-220 (.2-3.5)	12-48	94-98	Ind. Waste Application.

TABLE 4 (Continued)

Investigator	Reactor	Waste	COD Loading* #/d-1000 ft^3 (kg/d/m^3)	Detention Time (hr)**	COD Removal Eff. (%)	Significance
Wilson & Timpany 1973	1.9x5.7" Col, 1" polypropylene Intalox saddles ε = 0.83 T = 35°C	Dilute Waste Sulfite Liquor 1300-5300 mg/l BOD_5	125-375 (2.0-6.0)	89-95	27-58% BOD Removal	Ind. Waste Application, low pH inhibition, possible sulfite toxicity

* Based on total (empty bed) volume

** Based on initial unseeded void volume.

SECTION 2

SUMMARY

This report presents the results of an investigation and demonstration of the anaerobic filter for treatment of municipal treatment plant sludge heat treatment liquor. Heat treatment liquor resulting from the dewatering of combined heat treated primary and secondary sludges at municipal treatment plants can constitute a significant portion of the organic load to the sewage treatment facilities. At Muddy Creek, this load may be up to 23% of the design load to the aeration basins. Heat treatment facilities, such as at Muddy Creek, are designed for periodic operation, for example, 16 hours per day, 5 days per week. The return heat treatment liquor, therefore, not only constitutes a significant organic load, but also, due to the intermittent discharge of such a load, can cause a negative effect on the stability of the biological system and decrease its ability to maintain consistently low effluent BOD levels. This impact has been observed in data from the Muddy Creek plant and has been reported as a problem at other plants. The use of an anaerobic filter for treatment would reduce the organic load, and thereby reduce the variability in organic loading and mitigate the effect of the intermittent discharges of raw heat treatment liquor on effluent quality. Pretreatment of heat treatment liquor with the anaerobic filter is proposed as a cost effective and energy conserving process.

To demonstrate the anaerobic filter process, two anaerobic filter (0.6m x 0.6m x 1.8 m high, 680 l) pilot plants using 9.0 cm pall rings as filter media, were operated at the Muddy Creek sewage treatment plant of the Metropolitan Sewer District of Greater Cincinnati over a period of about 18 months. The studies were conducted in two phases. Phase I compared operation of the anaerobic filter at the mesophilic (35°C) and thermophilic (48°C) temperature ranges, as well as with a range of influent heat treatment liquor characteristics. The Muddy Creek plant heat treatment system was undergoing initial startup and due to odor problems was operated intermittently. Additional HTL was obtained from the nearby Mill Creek STP system. In Phase II, the anaerobic filters were operated in the mesophilic temperature range at different loading levels. A consistent heat treatment liquor supply was obtained from the Jackson Pike STP, Columbus, Ohio.

In addition to the field pilot studies, a small scale laboratory anaerobic filter and complete mixed conventionally loaded anaerobic digestors were operated with HTL feed.

Activated sludge pilot plants receiving treated and untreated heat treatment liquor, and primary effluent from the sewage plant were operated for several weeks. Data from these units were used to compare performance, and to develop design parameters for comparison of aerobic alternatives with the anaerobic filter.

Heat treatment liquor samples contained from 3000 mg/1 to 12,000 mg/1 COD, and 1100 mg/1 to 6100 mg/1 BOD. The pilot anaerobic filters were loaded at rates from about 1.5 kg COD/m^3/d to 10 kg COD/m^3/d. Acclimation of the filters and retention of methane forming organisms took considerably more time than initially anticipated. About 2-1/2 to 4 months of operation were required before the filters, seeded with digesting sludge, were achieving reasonably good removals and producing gas. Approximately 0.5 m^3 of gas was produced per kg COD removed. The gas contained from 65 to 70% methane.

The laboratory anaerobic filter, which contained 1.6 cm pall rings was loaded up to 20 kg COD/m^3/d. Analysis of solids content at the conclusion of the study indicated the lab column contained mostly attached growth, about 26 kg solids/m^3, compared to 15.2 kg solids/m^3 in Column 1 (60% attached), and 8.7 kg solids/m^3 in Column 2, (95% attached). The higher solids content in the lab filter would indicate greater retention and build up of methane formers in the smaller media. Somewhat higher removals were observed in the lab columns. Removal rates, based on COD to solids loading, were roughly comparable in the lab column and pilot Column 2, however, removals in the pilot filters were still gradually increasing with time, at the conclusion of the field studies.

Based on the results of the pilot and lab column results, a somewhat conservative detention time of 1.5 days was selected to develop a design of an anaerobic filter for cost comparison purposes. The loading of HTL would be in the order of 7.1 kg COD/m^3/d and based on 10 kg attached growth per m^3, the COD loading would be 0.71 kg COD/kg solids/d.

The performance of the pilot columns indicated removals of up to 63% COD, in Phase I and up to 70% COD and 85% BOD, in Phase II, while the lab column COD removal was in the order of 70 to 80% and BOD removal 85 to 95%. About 10 to 15% of the COD was determined to be non-biodegradable. Removals are based on total influent and filtered effluent samples to eliminate variability due to effluent solids.

The aerobic pilot study, conducted for about 1 month, indicated that using the detention time and organic loadings designed for the Muddy Creek plant, heat treatment liquor could be adequately treated. During the study period, there was no significant difference in performance and removals, between the unit receiving anaerobic filter effluent and the unit receiving raw heat treatment liquor. Oxygen requirements and sludge production, based on the amount of COD removed was similar for the two systems. The higher loaded system receiving raw heat treatment liquor required more oxygen and produced more total sludge than the system receiving treated heat treatment liquor. The raw sewage was quite weak, thus both systems were considerably underloaded when compared to the design for the treatment plant. This limit-

ed study involved continuous feed at constant rates, thus the potential detrimental effect of an intermittent heat treatment liquor load on performance, as was apparent based on limited full scale plant data, was not observed.

Preliminary capital and operating cost estimates were made based on the process sizing design. The estimates were made for an anaerobic filter using the design volume, 340 m^3 HTL per day for the Muddy Creek plant, and the selected design parameters. The preliminary design for cost estimating comparison is based on a 5 meter media depth in the filter which is somewhat less costly than the use of the 1.8 meter depth of media studied. Further testing is recommended to verify the use of a deeper media and the potential benefit of step feeding. Cost estimates were also made for the incremental aeration and sludge handling capacity designed into the Muddy Creek plant to handle return raw heat treatment liquor, and for a separate aerobic pretreatment system for heat treatment liquor.

The results of the cost estimate comparison are:

	Estimated Capital Cost	Annual Operation Cost	Annual Energy Requirements KW
Anaerobic Filter			
A. No credit for Methane Gas	$470,000	$28,000	15
B. Credit for Methane Gas	$470,000	-$17,000	-135
Aerobic Treatment			
A. Incremental Plant Cost	$535,000	$56,000	78
B. Separate Pretreatment	$1,015,000	$78,000	80

Based on this cost estimate, the anaerobic filter appears to be a cost effective and energy conservative process. A nine year pay off period at 8% interest would be required to justify the anaerobic filter in an existing plant designed for or with capacity for return heat treatment liquor. Based on operating cost savings, it does not appear that an anaerobic filter should be installed at Muddy Creek at this time. The anaerobic filter would be much more cost effective, however, for inclusion in the design of new treatment facilities, or facilities contemplating the addition of sludge heat treatment, compared to the incremental cost of aeration facilities, or separate aerobic pretreatment of the heat treatment liquor.

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE

SECTION 3

CONCLUSIONS

1) The anaerobic filter is an effective process for removal of substantial quantities of soluble, biodegradable organic material from heat treatment liquor. Removals of up to 70% COD and 80% BOD are projected using a design of 1.5 days detention time and a loading of 7.1 Kg COD/m^3/d with the anaerobic filter at 35°C. The heat treatment liquor contains 10-15% non-biodegradable COD.

2) The anaerobic filter is less costly than separate aerobic pretreatment, or combined aerobic treatment of heat treatment liquor, and has lower operating costs than aerobic treatment alternatives. There can be a significant cost credit for the heating value of the gas produced by anaerobic treatment.

3) To initially establish growth of methane formers in the anaerobic filter, additional buffering chemicals should be added to the heat treatment liquor to maintain optimum pH of 6.8-7.2. However, once methane formers are established, the heat treatment liquor contains sufficient alkalinity, both bicarbonate alkalinity and that due to conversion of organic nitrogen to ammonia, to maintain pH within an operational range of 7 to 8. Acclimation of an anaerobic filter to heat treatment liquor at high loadings can be enhanced by seeding with digesting sludge, however, from 2 to 4 months or more of operation are required to build up a population of methane formers.

4) At the design detention time and loading rates, the biological growth in the filter will be primarily attached to the media and most of the influent solids and suspended growth will be washed out.

5) The action of the gas produced and thermal currents within the filters resulted in an approximately completely mixed regime in the anaerobic pilot filters.

6) Raw and anaerobically treated heat treatment liquor can be adequately treated with primary sewage effluent in an aerobic activated sludge system with sufficient aeration basin and aeration capacity.

7) Maximum removals by anaerobic treatment based on data from a laboratory filter using small media, are in the order of 70 to 80% COD and 85 to 95% BOD for heat treatment liquor.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.) (4-76)

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE

SECTION 4

RECOMMENDATIONS

1) Anaerobic filter pretreatment of return sludge heat treatment liquor should be considered as a practicable and potentially cost effective alternative to aerobic treatment of heat treatment liquor in a separate system or combined with primary sewage effluent.

2) To further develop and optimize design of an anaerobic filter treatment system, and to achieve maximum cost/benefit potential, further evaluation and comparison of alternative configurations of the anaerobic filter should be investigated in further pilot plant studies. Configurations that should be studied include:

- Upflow mode as studied in this investigation at greater depths and loading rates
- Step feed upflow system
- Combination of a completely mixed tank preceding the anaerobic filter in which solids settled from the filter or separated from the filter effluent could be accumulated and recycled to increase volatile acid and methane formation rates, thereby reducing overall system size
- Fluidized bed system using small suspended medium and effluent recycle
- Use of other types of media to increase solids retention without excessive plugging and to reduce overall system size and cost.

3) Further pilot studies of the anaerobic filter should include an evaluation of separation and recycle of effluent solids. This technique may increase the rate of acclimation and the equilibrium population of methane organisms in the system and thus decrease detention time and increase removal rates.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

EPA-287 (Cin.) (4-76)

SECTION 5

PILOT PLANT AND EXPERIMENTAL PROGRAM

ANAEROBIC FILTERS - PILOT UNITS

Figure 3 is a flow diagram of the pilot anaerobic filters, and Figure 4 shows a picture of the units, taken in September, 1978. The heat treatment liquor storage tank was a 17,000 liter ferric chloride feed tank originally designed for use with the plant's vacuum filter system. A valve and tee were connected to the plant's heat treatment liquor decant tank to permit filling the ferric chloride tank with heat treatment liquor. FMI piston metering pumps were used to feed constant flows to the two filters. Two water heaters each with a 40 liter capacity were used to raise the influent temperature to maintain temperatures required in the filter. These heaters were next to the columns to minimize heat loss in the lines from the heaters to the columns.

The two filters were 0.6 x 0.6 x 4 meter steel columns with a conical bottom. Sample taps and thermometer ports in plexiglass windows were placed at 0.3 meter intervals from 0 to 1.5 meters and at 0.6 meter intervals from 1.5 to 2.7 meters. A steel superstructure supported the columns and provided access to the top of the columns. Heating tapes were placed at 0.3 meter intervals along the length of the column and were controlled by temperature controllers with probes at the 0.9 meter level.

The top of the columns were covered by plexiglass plates which contained a gas port. The gas from each filter went through two moisture traps, then through dry "Rockwell" gas meters which were located between the columns. A check valve was placed after the meters to prevent any air from getting into the columns. The filter effluent lines were raised a half foot above the column effluent taps to prevent gas escape and were vented to prevent siphoning.

The columns were initially filled to ten feet with Norton "Actifil" 90 TM Media. The plastic media are cylindrical in shape, 9 cm long x 9 cm diameter (about 3 1/2" x 3 1/2"), have a porosity of 95%; a surface area of 101.7 m^2/m^3, and weight of 44 kg/m^3.

Phase I Program

In the initial program planned for Phase I, one unit was to be operated in the thermophilic temperature range (49°-55°C) and the second in the mesophilic (35°-38°C) temperature range. The systems were to operate in parallel at selected detention times and constant loading rates for the first six months. The program, however, could not be exactly followed as planned

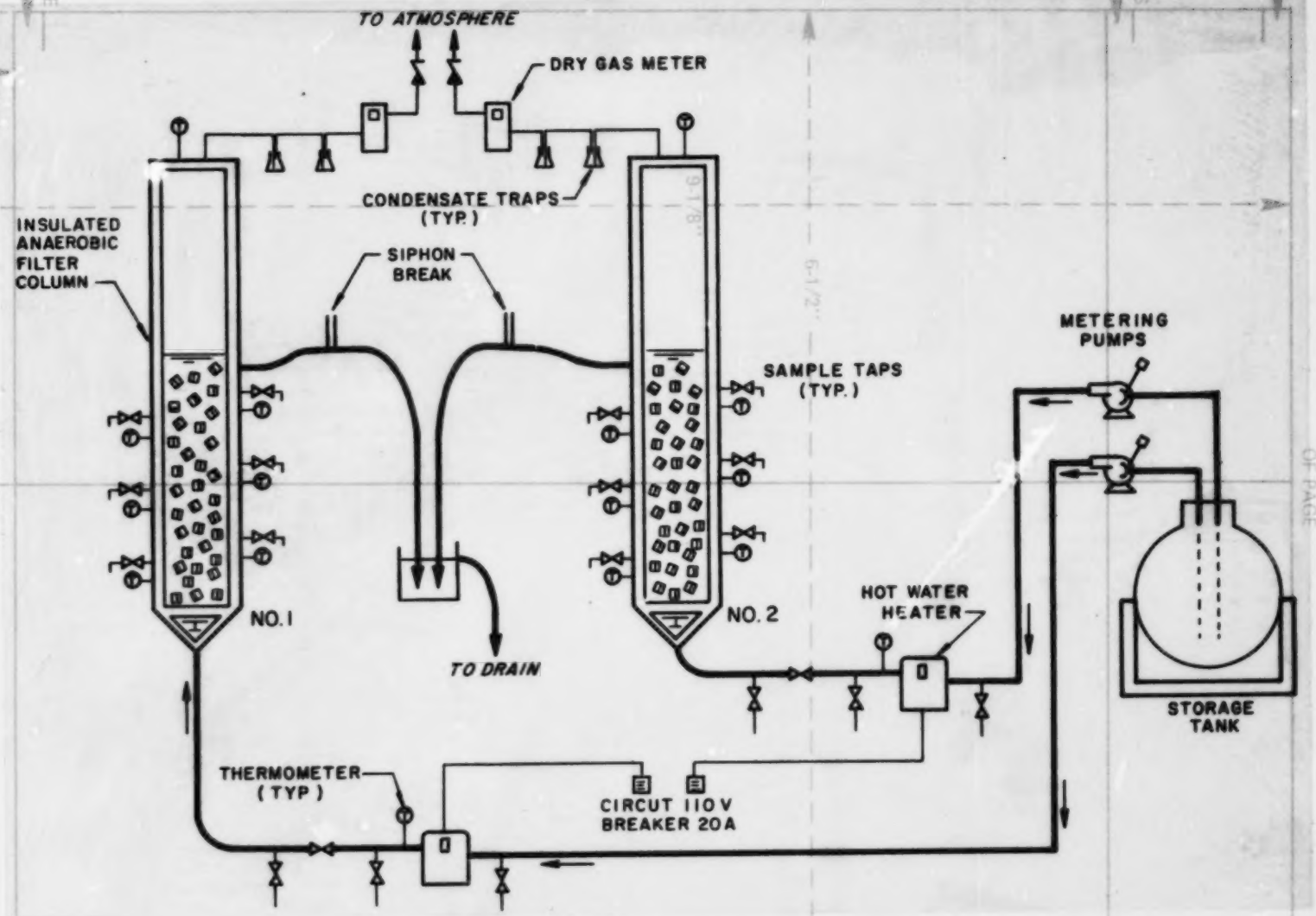


Figure 3. Anaerobic filter pilot units—schematic.

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE

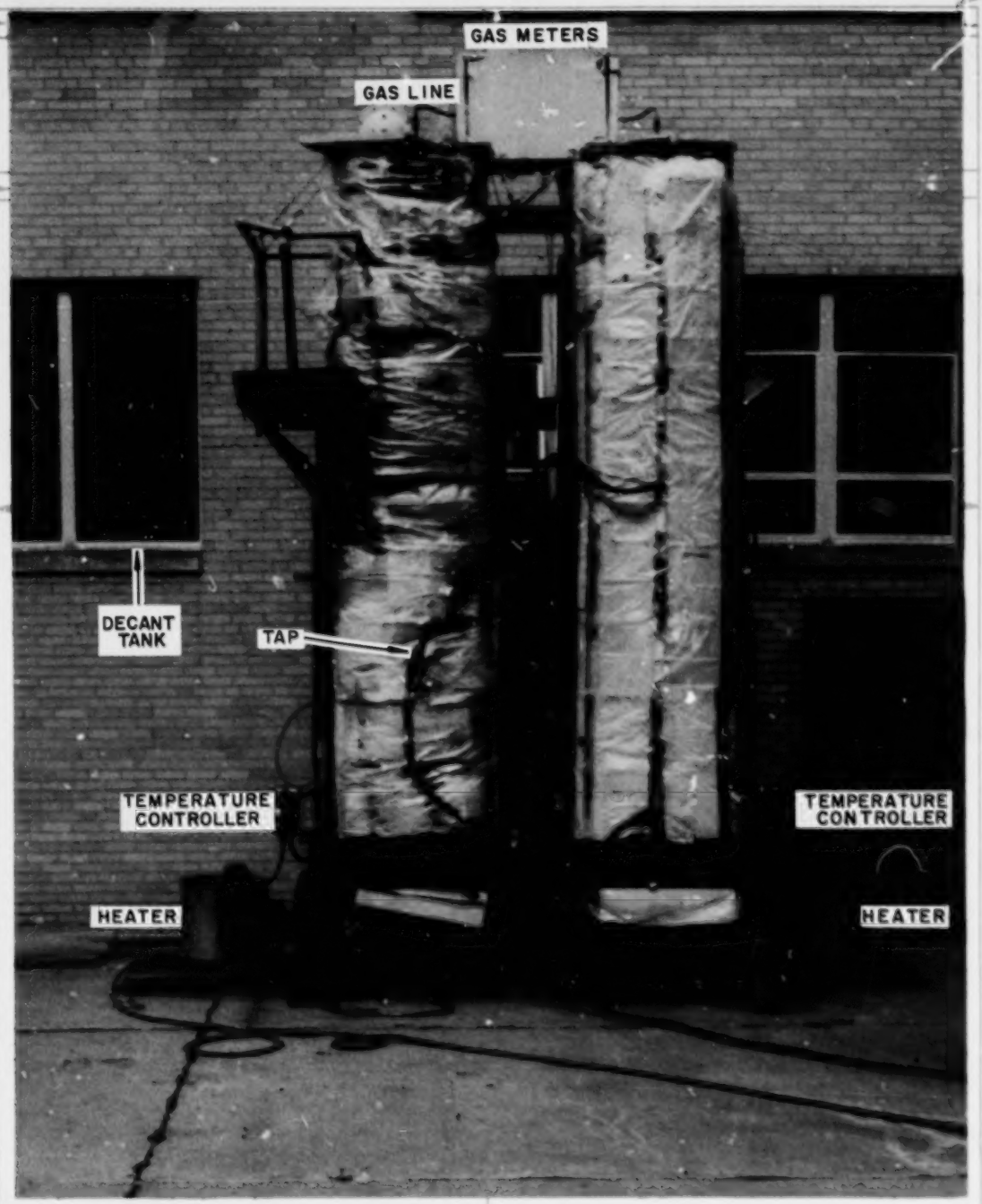


Figure 4. Pilot anaerobic filters.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA. OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

EPA-287 (Cin.)
(4-76)

due to a long acclimation period caused by occasional lack of heat treatment liquor supply and variable COD and solids concentration of the available liquor. The Muddy Creek heat treatment system started up in April 1977, however, was operated intermittently only until June when it was shut down due to air pollution problems. To proceed with the study, heat treatment liquor was obtained from the Cincinnati Metropolitan Sewage District's Mill Creek Plant. Consequently, without being able to obtain fresh supplies of heat treatment liquor, the liquor stored degraded gradually, thus the influent COD to the filters varied. To maintain a relatively constant COD loading to the filters, it was necessary to vary the flow resulting in varying detention times. The intermittent supply of HTL and problems with temperature control resulted in the extended acclimation period. The experimental schedule followed in Phase I is shown in Table 5.

In addition to the routine analysis performed during the study, several special experiments were conducted. These included dye tracer studies, depth sampling, effluent recirculation, and sludge solids recirculation in the bottom section of the filter columns. The dye studies were run on the unseeded column prior to the start of the field evaluations, and repeated again after the columns were operating under standard conditions. This test examined the hydraulic characteristics of the filters. Depth sampling studies were performed to determine the change in waste characteristics through the column. Recirculation of effluent was conducted to determine the maximum COD reduction achievable, and internal recirculation was tried to evaluate the effect of increased mixing within the lower section of the filter.

Due to the delays caused by lack of heat treatment liquor, and slow acclimation of the filters, the study extended into the colder months resulting in temperature control problems. As a result, operating data was only obtained for about 2 months at relatively stable conditions. Consequently, the study period was extended, and a Phase II program was initiated the following spring.

Phase II Program

Pilot plant modifications were made and included installation of new insulation and weather proofing on the filters, replacement of hot water heater temperature controls and heating elements, reduction of the media depth to 1.83 feet, and provisions for mixing and recirculation. The filters were flushed with air and water to remove existing solids and reseeded with active digesting sludge. Heat treatment liquor was transported by tank truck from the Columbus Jackson Pike STP, which had a reliable, operational heat treatment system, to the 17,000 liter storage tank at the pilot plant. Table 6 presents the program followed in Phase II. A longer time was required than anticipated to attain relatively steady state removal at the initial loading condition. Loading rates from 1.7-9.4 kg COD/m^3/d (106-587 lbs/1000 cu. ft./d) were tested and covered the range planned. The sample collection and analysis schedule for Phase II was essentially the same as Phase I. A tracer study was performed during the second phase along with four depth studies. At the conclusion of the program, media were removed from the column for examination and determination of attached solids. Analysis of the off-gas for methane and carbon dioxide were conducted.

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD. BEGIN SECTIONS HERE

TABLE 5. ACTUAL EXPERIMENTAL SCHEDULE - PHASE I

Months 1977	Description	Detention Time (Days)	COD Load kg COD/m^3/d
January - April	Procurement of equipment construction of pilot plants and installation		
April - June	Initial seeding and acclimation	9.0	2.0
June - September	Evaluate operating condition-1 Mesophilic Column 1 (35°C) Thermophilic Column 2 (48°C)	2.0-4.5	2.0
September - October	Evaluate operating condition-1 Columns 1 and 2 Mesophilic mixing and recycle experiments	4.2	≃ 2.0
October - November	Evaluate operating condition-2	2.8-3.8	2.8

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.) (4-76)

TABLE 6. ANAEROBIC FILTER STUDY PROGRAM AND SCHEDULE - PHASE II

		Date 1978
I.	Modify Pilot Plants	March 22 - April 20
	New Heat and Temperature Control Additional Column Insulation	
	Media Modifications -	
	Inspect and Repair or Replace Equipment as Necessary	
II.	Pilot Plant Operation (2 Units)	
	Acclimation -	to Aug 1
	Evaluation @ 3.9 kg COD/m^3/d @ 1.9 kg COD/m^3/d	to Aug 23
	Acclimation to New Loading Rates	to Sept 7
	Evaluation @ 9.0 kg COD/m^3/d @ 1.9 kg COD/m^3/d	to Sept 15

Table 7 shows the analytical schedule followed on a regular basis during the course of the pilot plant operation, both in Phase I and Phase II. Tests were performed on limited number of samples sent to Hydroscience lab in Phase I and regular analyses at the pilot plant in Phase II.

Aerobic Pilot Study Program

During Phase II, a limited study was conducted to evaluate the effect of heat treatment liquor and anaerobically treated heat treatment liquor on aerobic treatment of Muddy Creek primary effluent. A schematic flow diagram of the aerobic pilot system is shown in Figure 5. It was desired to operate the aerobic systems at the design loads and detention times for the Muddy Creek plant (year 2000), and under two conditions, one with heat treatment liquor return, and one with anaerobically treated heat treatment liquor return to the aeration basin. The design aeration basin detention time was 6 hours. The aeration basins were seeded with mixed liquor from the Muddy Creek Plant. The program is shown in Table 8. Primary effluent was fed to both aeration basins for 2 weeks prior to the introduction of heat treatment liquor. Unit 1 received untreated heat treatment liquor and unit 2 received the effluent from anaerobic filter #1. The raw and treated heat treatment liquor was collected each day to prevent any degradation. The sampling and analytical schedule is shown in Table 9.

TABLE 8. AEROBIC EXPERIMENTAL PROGRAM

Date 1978	
8/13-8/24	Evaluation and start up of systems fed Muddy Creek primary effluent without heat treatment liquor
8/24-9/8	Evaluation of systems with projected flow rates of primary effluent with treated or untreated heat treatment liquor
9/8-9/15	Evaluation of systems with projected primary effluent flow and double the expected heat treatment liquor flow

LABORATORY ANAEROBIC BENCH DIGESTORS

Bench-scale completely mixed anaerobic digestors were used to study the biodegradeability of heat treatment liquor being fed to the pilot anaerobic filters. This study was conducted at Hydroscience's Westwood Laboratory using 3.0 liter volume bench-scale digestors. The digestors were placed on magnetic stirrers inside an incubator where the temperature was controlled by the setting on the incubator. The magnetic stirrers were operated intermittently to maintain complete mixing of the systems. Gas production was measured by displacement of liquid in a gas collector. Unit A was seeded with sludge from the pilot mesophilic filter operating in Cincinnati and Unit B was seeded with digestor sludge from Bergen County STP. The planned detention time was 24 days. The units were fed twice a week with 500 and 375 milliliters of heat treatment liquor. Analysis was performed on the liquid extracted from the digestors at the time of feedings. Table 10 shows the analytical schedule.

TABLE 7. ANALYTICAL SCHEDULE
ANAEROBIC PILOT FILTERS

	Monday	Thursday
COD_T (Reflux-Rapid)*	I, E1, E2	I, E1, E2
COD_f (Reflux-Rapid)*	I, E1, E2	I, E1, E2
Volatile Acids	I, E1, E2	I, E1, E2
TKN	I, E1, E2	
NH_3-N	I, E1, E2	
SS	I, E1, E2	I, E1, E2
VSS	I, E1, E2	
TS	I, E1, E2	I, E1, E2
TVS	I, E1, E2	
Alkalinity	I, E1, E2	I, E1, E2
BOD_T	I, E1, E2	I, E1, E2
BOD_F	I, E1, E2	I, E1, E2

I - Influent; E1, E2 - Effluent Column 1 and 2 Respectively

Gas analysis - twice a month

The following readings were taken every day:

Flow
Temperature - Influent, Effluent and Taps
Gas Production
pH

* A Rapid COD test was used in place of reflux during the acclimation period of Phase I.

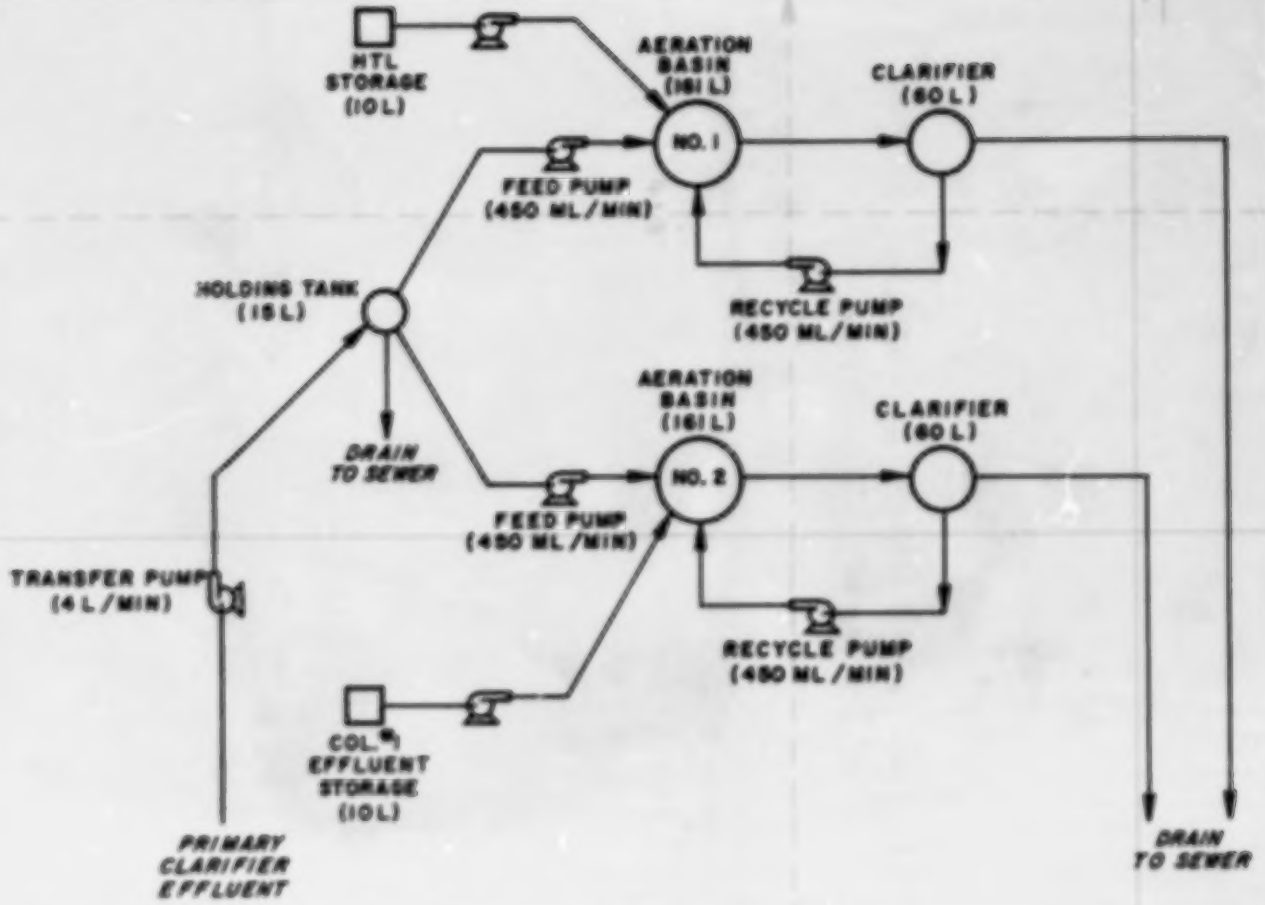

HTL STORAGE (10 L)
AERATION BASIN (16 L) NO. 1
CLARIFIER (6 L)
FEED PUMP (450 ML/MIN)
HOLDING TANK (15 L)
RECYCLE PUMP (450 ML/MIN)
AERATION BASIN (16 L) NO. 2
CLARIFIER (6 L)
DRAIN TO SEWER
FEED PUMP (450 ML/MIN)
TRANSFER PUMP (4 L/MIN)
RECYCLE PUMP (450 ML/MIN)
COL. EFFLUENT STORAGE (10 L)
PRIMARY CLARIFIER EFFLUENT
DRAIN TO SEWER

Figure 5. Aerobic pilot units -schematic

TABLE 9. SAMPLING SCHEDULE
AEROBIC PILOT UNITS

Test	Frequency	Primary Effluent	Raw MTL	Treated MTL	Effluent Unit #1	Effluent Unit #2	MLSS #1	MLSS #2
COD Total	2/wk	X	X	X	X	X	-	-
COD Filtered	2/wk	X	X	X	X	X	-	-
BOD Total	2/wk	X	X	X	X	X	-	-
BOD Filtered	2/wk	-	X	X	-	-	-	-
SS	2/wk	X	X	X	X	X	-	-
VSS	2/wk	X	X	X	X	X	-	-
MLSS	2/wk	-	-	-	-	-	X	X
MLVSS	2/wk	-	-	-	-	-	X	X
Flow	7/wk	X	X	X	-	-	-	-
Oxygen Uptake Rate	2/wk	-	-	-	-	-	X	X
D.O., T, pH	5/wk	-	-	-	-	-	X	X
Settling Rate	2/wk	-	-	-	-	-	X	X

TABLE 10. LABORATORY ANAEROBIC BATCH DIGESTORS ANALYTICAL SCHEDULE

Analysis	Tuesday and Friday	Analysis	Tuesday and Friday
COD_T (Reflux)	I	pH	I,E
COD_F (Reflux)	I,E	Alkalinity	I,E
BOD_T	I	Volatile Acids	I,E
BOD_F	I,E	TKN	I
SS	I,E	NH_3-N	I
VSS	I,E		

I = Influent
E = Effluent of each digestor
Gas production and temperature was measured every day.

The initial loading on the digestors was planned for 0.02 kg. COD/kg. VSS-d based on a COD concentration of 10,000 mg/l and a VSS concentration of 20,000 mg/l.

LABORATORY ANAEROBIC FILTER

Hydroscience conducted inhouse funded research concurrent with the pilot plant filter study utilizing a laboratory anaerobic unit which had been seeded and used to determine treatability of other strong wastes. The anaerobic filter used was a 5 cm diameter, 1.3 m high plastic tube containing 1.2 m of Norton Actifil Media, 16 mm diameter x 16 mm (0.63" x 0.63"). The media characteristics were, porosity - 0.87, and surface area - 341 m^2/m^3. The volume of the column including the clean media was 2.1 liters. Temperature control was provided by a heating tape which was activated by a temperature probe at the 1.2 m level of the column. Gas production was measured by a Precision Wet Test Meter. An FMI (0-13 ml/min) metering pump was used to feed the filter.

The purpose of the lab program was to use the already seeded and acclimated anaerobic column to determine removal levels of BOD and COD from heat treatment liquor, and to anticipate results and time frames which could be expected in the full scale pilot plant. The unit was operated at several loading rates and detention times during the study. Influent feed was sent to Hydroscience from the pilot plant in Cincinnati. The loading rates studied ranged from 4.0 to 21.0 kg $COD/m^3/d$ (250 - 1310 lbs. $COD/1000\ ft^3/d$) over the course of the study. The laboratory program that was followed is shown in Table 11, and the sample and analytical schedule is shown in Table 12.

TABLE 11. LABORATORY ANAEROBIC FILTER PROGRAM

Date 1978	HTL Supply	Loading kg COD/m^3/d	Det. Time Days
4/7-4/30	1	3.9-4.7	1.3-1.6
5/1-5/8	1	4.8-7.7	0.7-1.3
5/9-6/12	1	5.5-8.0	0.6-0.8
6/13-6/30	2	9.3-12.6	0.7-0.9
7/1-7/13	2	11.0-13.0	0.6
7/14-7/27	2	7.0-9.4	0.6-0.8
7/28-8/7	3	15.7-17.7	0.5-0.6
8/8-8/18	3	18.0-22.8	0.5
8/22-8/31	3	10.9-13.9	0.6

TABLE 12. LABORATORY ANAEROBIC FILTER SAMPLE AND ANALYTICAL SCHEDULE

Analysis	Tuesday	Friday
COD-Total (Reflux)	I,E*	I,E
COD-Filtered (Reflux)	I,E	I,E
BOD-Total	I,E	I,E
BOD-Filtered	I,E	I,E
Volatile Acids	I,E	I,E
TKN	I,E	
NH_3-N	I,E	
SS	I,E	I,E
TVSS	I,E	I,E
Alkalinity	I,E	I,E

The following readings were taken five times a week:

Temperature
Gas Production
pH
Effluent Volume

* I = influent
E = effluent

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD, BEGIN SECTIONS HERE

SECTION 6

ANAEROBIC FILTER PILOT PLANT RESULTS

PILOT PLANT OPERATION - PHASE I

Chronological Plots

The pilot plant filter units were seeded on May 11, 1977 with digesting sludge from the Lebanon, Ohio Sewage Treatment Plant digestors. Table 13 presents analyses conducted on the sludge. The heat treatment liquor (HTL) obtained from the Muddy Creek decant tank had a COD of 20,000 mg/1, about 2 to 4 times higher than historical data indicated. A relatively low flow of HTL was pumped to the systems. The acclimation period detention time was 9 days, and the loading about 2.0 kg COD/m^3/d. Filter Column 1 was operated in the mesophilic temperature range about 35°C, and filter Column 2 was operated in the thermophilic range, about 55°C. A chronological plot of operating conditions and performance during Phase I, May to December, 1977, is shown in Figure 6.

Analyses - Discussion of Data

Acclimation --

There was an immediate and rapid buildup of volatile acids in the filters, however, there was sufficient buffering capacity to generally maintain pH in the 6.5 to 7.0 range. The production of volatile acids occurred not only in the filter, but also in the HTL storage tank, indicating the easily degradable nature of much of the organics in the HTL. The presence of the volatile acids through June, and the relatively low gas production, indicated relatively little removal of COD. The methanogenic bacteria were not yet established in numbers sufficient to convert the volatile acids to methane and CO_2. The data during this period, however, showed some removals of COD, initially as high as 52 percent in Column 1, dropping to 25 to 35 percent in June, and in the range of 20 percent in Column 2. The higher removals in Column 1 probably were due to the fact that the seed sludge was acclimated to a temperature of about 35°, while the lower removal in Column 2 was indicative of adaptation of thermophilic organisms to the higher, 55°C temperature.

There has been some controversy in the literature with respect to toxic inhibition of methane formation by excessive concentrations of volatile acids. One source indicated that studies showed volatile acids up to 6000 mg/1 had no inhibiting effect, and that pH was the prime environmental factor. This study, however, did not consider thermophilic methanogenic bacteria. The high volatile acids during the initial operation in May and June may have caused or contributed to the slow acclimation and growth of methane formers.

BEGIN LAST LINE OF TEXT HERE
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Orig.) (4-76)

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE
6-1/2"

TABLE 13. ANALYSIS OF SEED SLUDGE FOR THE ANAEROBIC COLUMNS
(Digestor Sludge Lebanon, Ohio STP)

Physical Characteristics

Total Solids (mg/l)	48,300
Total Volatile Solids (%)	52
Suspended Solids (mg/l)	46,200
Volatile Suspended Solids (%)	51
Dissolved Solids (mg/l)	2,060

Chemical Characteristics

Chemical Oxygen Demand (mg/l)	40,760
Volatile Acids (mg/l as acetic acid)	0
Alkalinity (mg/l as $CaCO_3$)	6,350

Trace Metals

	(mg/kg dry solids)
Arsenic	180
Cadmium	15
Chromium	130
Copper	1,040
Iron	15,700
Mercury	11
Magnesium	304
Nickel	53
Zinc	1,820

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

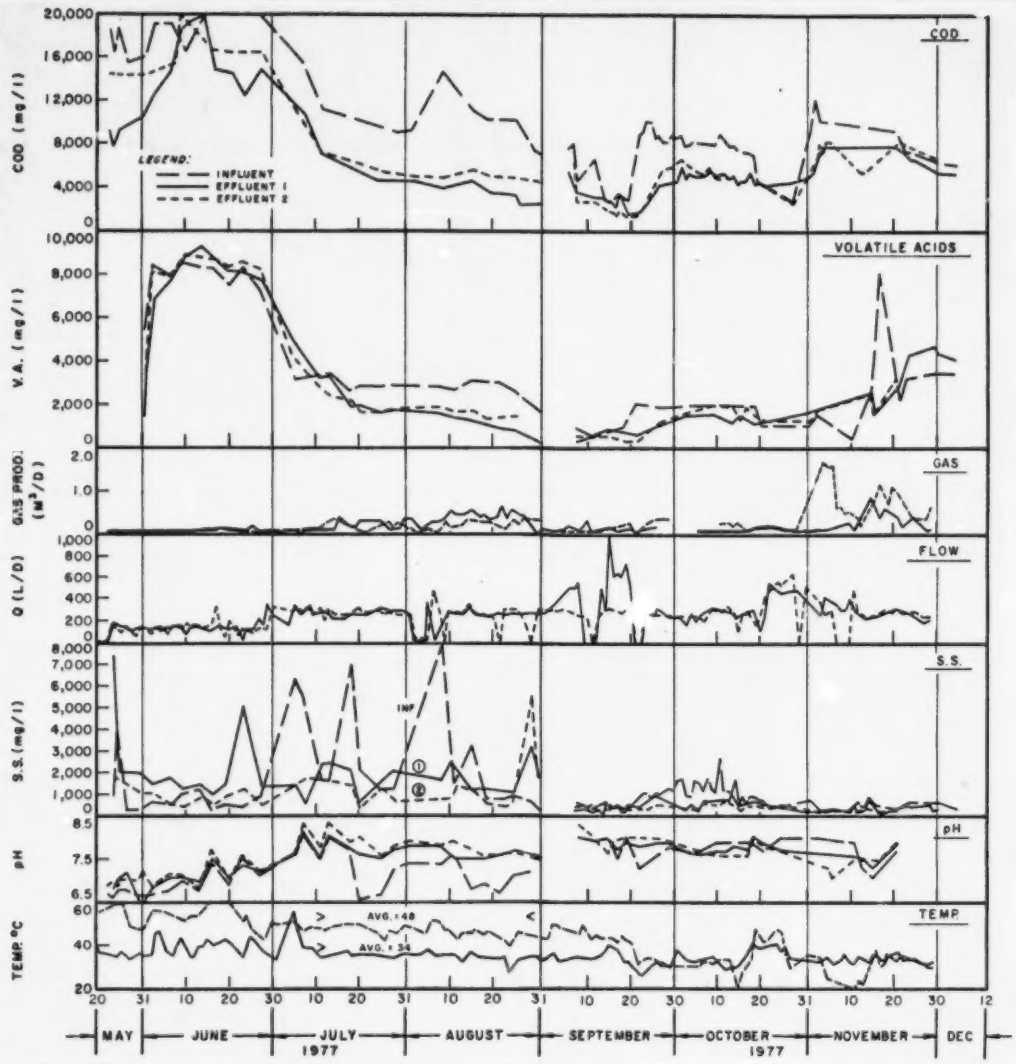


Figure 6. Phase I chronological plot.

The reduction in influent COD concentration in early July also resulted in a decrease in the volatile acid concentrations in the filters. Flow to the filters was maintained relatively constant, except for occasional minor excursions. The detention time in the filters during this initial period was approximately nine days, and based on experience with typical high rate digestors, should have been sufficient to permit establishment of operation with gas production.

Operation: May - June --

Influent suspended solids varied, depending on the degree of mixing in the feed storage tank, from 250 to 1300 mg/1. Influent solids reached rather high values on occasion, usually after the introduction of a new supply of HTL into the storage tank. Some HTL solids settled in the tank and these additions would resuspend previously settled solids. During May and June, solids in the Column 1 effluent were consistently in the 1000 to 2000 mg/1 range, indicating washout of influent solids, suspended sludge solids and newly grown biological solids. Column 2 solids loss was less than Column 1 but also averaged somewhat higher than the influent solids.

While temperature was generally near the desired levels in May and June, there were excursions due to rapid changes in weather, mechanical problems with the heaters and feed pumps, and in adjustments of the heater controls. The thermophilic column was initially held above 50°C but in later June, based on reported optimum temperatures in thermophilic anaerobic digestors during startup, the temperature in the thermophilic unit was reduced to 48°C. Through July and August, relatively good temperature control was maintained in the units.

Operation: July - August --

With the reduction in influent COD to about 10,000 mg/1 and corresponding volatile acid concentration reduction, and maintenance of optimum temperatures, both filters began producing significant amounts of gas with gradual increase in the daily gas production, starting in early to mid July. The flow rate was increased at the end of June to maintain COD loading at about 2.0 $kg/m^3/d$, at a detention of about 4 days. Concurrently, significant volatile acid concentration reduction and increased COD removal occurred, indicating the units were acclimating and retaining methanogenic organisms.

Column 1, operated in the mesophilic temperature range, produced a consistently lower effluent COD than Column 2, operated in the thermophilic range. This may have been due to a number of factors including less sludge solids (see depth study) and slower growth or a lag in acclimation of the thermophilic organisms. In any event, the results did not indicate any particular advantage of operating in the thermophilic range, as originally postulated, namely a higher rate utilization of volatile acids and more rapid acclimation. Accordingly, operation in the thermophilic range was abandoned and both units were operated in the mesophilic range commencing in late September.

During the July to August period, the decline in effluent COD and volatile acids was gradual, reflecting a slow buildup and retention of the methanogenic organisms in the anaerobic filters. Microbiological growth on the filter media and formation of settleable bacterial clumps proceeded at a slow rate, and undoubtedly a significant amount of new growth in the suspended form was being lost from the filter, as evidenced by the high effluent solids concentration. These occurrences are due to the slow growth rate and poor settleability of the methanogenic bacteria. It was anticipated that seeding the filters with digesting sludge would accelerate the acclimation process, however, this apparently was not the case in this phase of the study. As shown by the lab digestor study, the seed used in Cincinnati was of a poor quality when compared to the sludge from Bergen County's digestor.

Loading, detention, gas production and COD removals achieved during two periods in August for each column are summarized in Table 14. The volatile acids concentration in the effluent was significantly higher than maximum values of a few hundred mg/l from previous laboratory scale studies. This indicated that the units had not fully "acclimated." The continuing gradual improvement indicated that the units had not reached an equilibrium condition. The COD removal was significant when considering that a fraction of the COD was non-biodegradable. The gas production per kilogram of COD, however, was lower than the 0.4 to 0.6 $m^3/kg\ COD_R$ values found in previous studies and literature data, indicating low methane formation.

Depth Study --

A depth study of each filter was performed on August 10th and the results are presented in Table 15 and Figure 7. There was no decrease in the organic level from tap 1 to tap 9 in either column. Column 1 had a uniform suspended solids concentration for the first 1.5 meters. Column 2 showed less organic removal but had less solids above the 0.9 meter level than Column 1. Most of the organic removal appeared to occur in the first 3 meters in both columns with some additional removal up to tap 3. Based on the mixing observed in the tracer study, however, it could be theorized that removal was relatively uniform throughout the lower sections of the filter, which contained significant solids levels.

Recirculation Study --

On August 26th, the effluent from Column 1 was recirculated back through the influent port, with no influent flow. The purpose was to determine the maximum reduction in COD, volatile acids, and BOD that could be achieved in the anaerobic filter. The effluent was recirculated from August 26th through September 2nd. Table 16 and Figure 8 present the data collected from the study. Gas production dropped off to less than 0.006 cubic meters per day concurrent with a reduction in volatile acids from 780 to 170 mg/l. The resulting soluble effluent BOD, and COD were 500 and 1700 mg/l, respectively.

The results indicate that the maximum COD reduction which could be expected was about 68 percent and maximum BOD reduction about 83 percent at 4 to 5 days theoretical detention. These results can be compared to the 59 percent removal of COD and 72 percent removal of BOD achieved by the filter under continuous flow conditions at a calculated detention of about 4 days.

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD, BEGIN SECTIONS HERE

TABLE 14. PHASE I - AUGUST OPERATION SUMMARY

Col. #	Date 1977	Flow l/d	Time Days	Loading kg COD/m^3/d	Gas Prod. m^3/d	Avg. Temp. °C	COD Removed %	m^3 Gas / kg COD_R
1	8/15-20	274	4.1	2.39	.42	34	59	.26
	8/20-26	269	4.2	2.13	.48	32	63	.31
2	8/16-19	257	4.4	2.24	.31	46	48	.29
	8/23-26	302	3.7	2.39	.29	43	47	.23

6-1/2"
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.) (4-76)

TABLE 15. DEPTH STUDY ON 8/10/77

	COD_F mg/l	Suspended Solids mg/l
Influent	5040	3000
Column 1		
0.3 meters	3610	26060
0.6 meters	3820	24560
0.9 meters	3610	28880
1.2 meters	3650	24300
1.5 meters	3530	26280
2.1 meters	3700	16100
2.7 meters	3650	1860
Effluent	3570	2460
	Flow = 215 l/d	Temp. = 35°C
Column 2		
0.3 meters	4450	36780
0.6 meters	4660	37780
0.9 meters	4200	28800
1.2 meters	4240	-
1.5 meters	4200	6660
2.1 meters	4280	1120
2.7 meters	4450	1110
Effluent	4280	810
	Flow = 239 l/d	Temp. = 47°C

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE

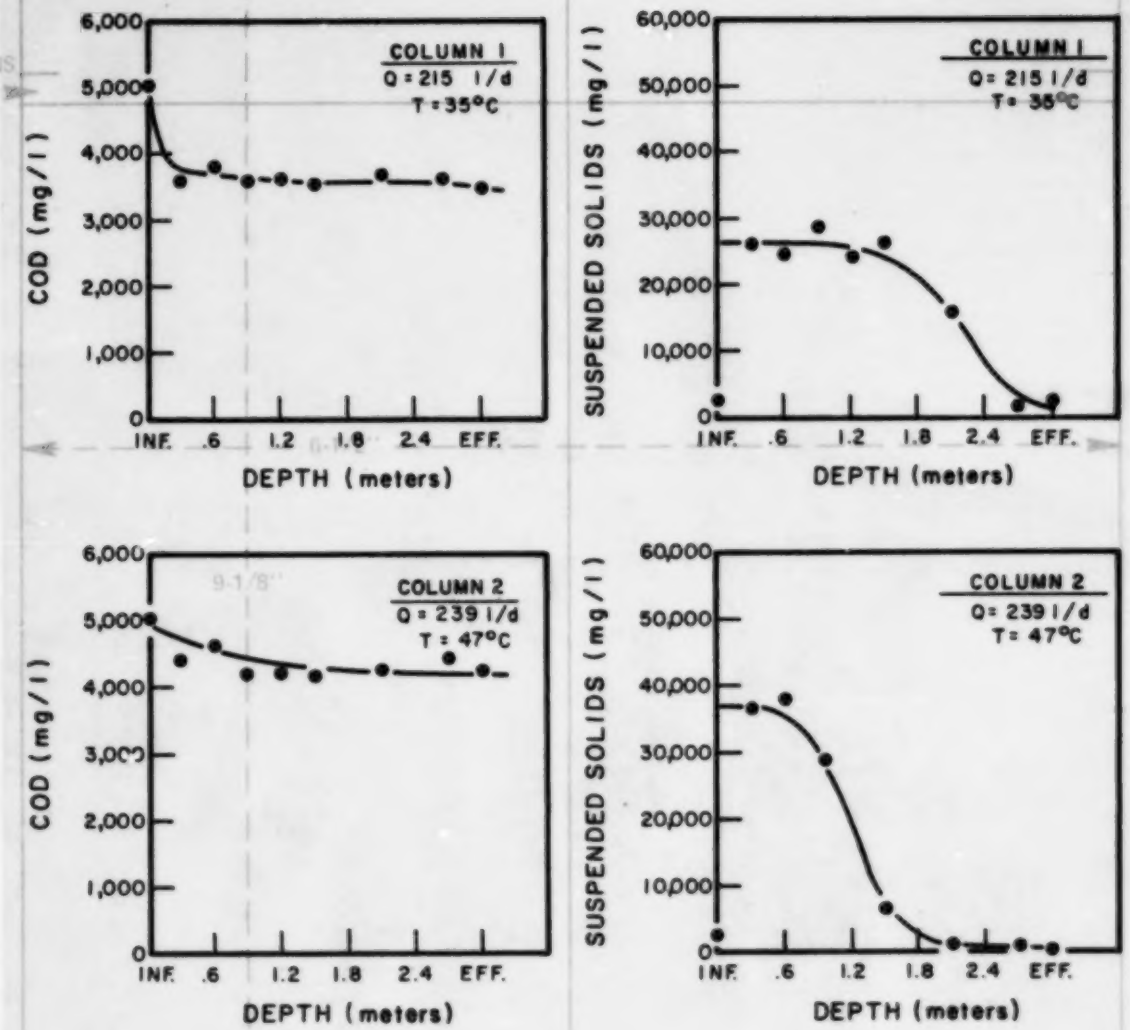


Figure 7. Depth study—August 10, 1977

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

EPA-287 (Circ.)
(4-76)

TABLE 16. RESULTS OF RECIRCULATION OF EFFLUENT
COLUMN 1

Date	Gas Production (m^3/d)	INFLUENT (mg/1)					EFFLUENT (mg/1)				
		COD		BOD	Vol.		COD		BOD	Vol.	
		Total	Soluble	Soluble	Acids	SS	Total	Soluble	Soluble	Acids	SS
8/26	.425	5356	4846	4600	2668	990	3037	2210	1277	784	1380
(before recirculation)											
8/27	.417										
8/29	.147						4476	1865		517	3216
8/30	.039						4500	1700			
8/31	.019						2200	1800	500	170	2906
9/02	.006										

Flow Rate - 270 1/d

* Rapid Test

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD, BEGIN SECTIONS HERE

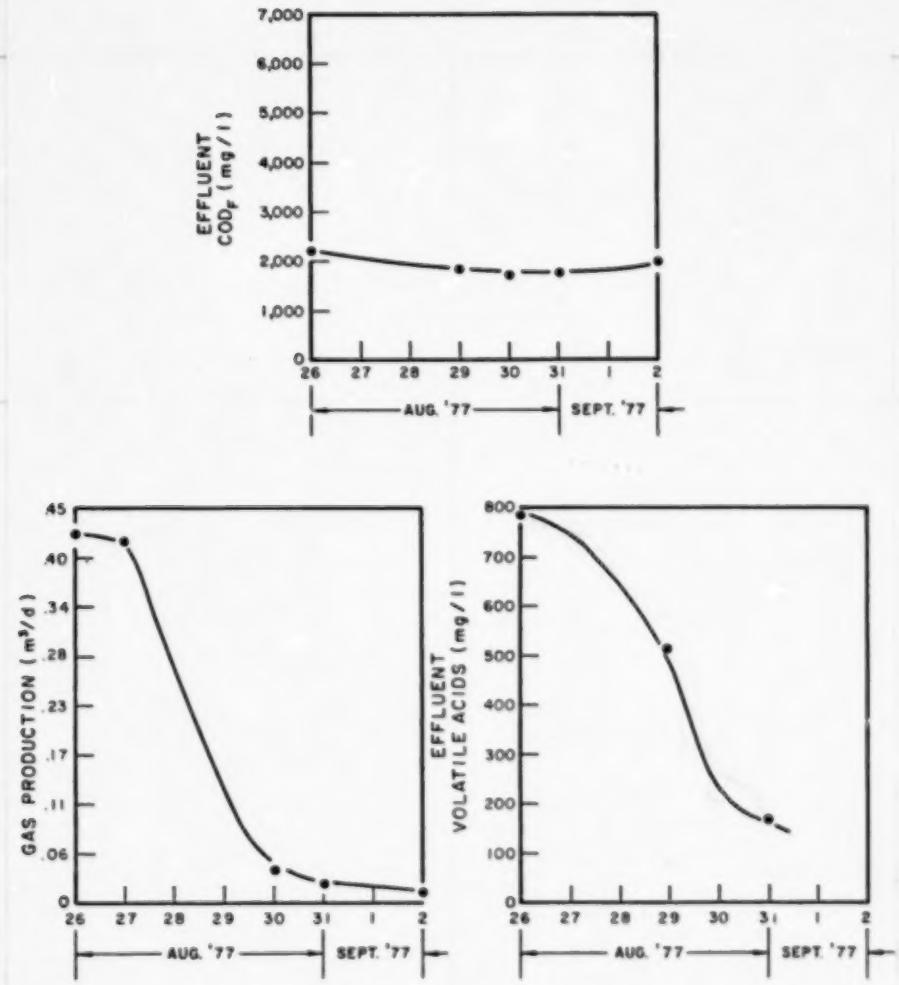


Figure 8. Recirculation study – column no. 1

BEGIN LAST LINE OF TEXT
3/8"
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

EPA-287 (Cin.)
(4-76)

September - November --

During this period, generally poor performance of the anaerobic filters was observed. Both filters were operated in the mesophilic temperature range and removed 25% of influent COD. This was due to a number of contributing factors:

(1) Inconsistent supply of heat treatment liquor due to the complete shutdown of the Muddy Creek, and the intermittent operation of the Mill Creek heat treatment systems. Long periods of storage of the liquor trucked to the pilot site led to significant organic degradation and low feed concentrations.

(2) Possible inhibition in October due to the hydrolysis of organic nitrogen to ammonia. The pH in the columns during this period ranged from 7.5 to 8.0 which resulted in unionized ammonia concentration in the range of 20 to 80 mg/1. Toxicity would not be a problem at these concentrations but inhibition may have resulted during the generally upset conditions that existed.

(3) Temperature control, particularly during the colder weather in late October and November.

(4) Solids washout which contributed to the slow development of the system.

In December, due to the lack of an adequate heat treatment liquor supply and increasing difficulty in maintaining desired temperature, the pilot plant system was shut down. After repairs and modification, the system was restarted (Phase II) in April, 1978.

Media Replacement --

The top 1.5 meters of media was taken out of Column 2 and was replaced by .61 meters of a similar configuration but smaller, 4 cm, in size than the 9 cm media in the filter in late September. The purpose was to try to effect better solids capture in the filter and thus increase the capture of methanogenic organisms. Column 2 was put back on line on October 6th and operated in the mesophilic temperature range. Gas production increased slowly in the following 3 weeks during which soluble COD removals of 10 to 20% were observed. As previously mentioned, influent and effluent solids were considerably lower during this period and no significant difference in effluent solids from the two columns was observed.

Tracer Studies - Phase I

A dye analysis was performed prior to seeding the columns with biological sludge in May. Rhodamine WT® dye was used as the tracer substance and a continuous feed method was employed. A known concentration of dye was added until the effluent dye concentration matched the influent dye concentration.

Data was collected on both the high and low temperature columns. Initially, the flow rates were set at 2,200 ml/min for filter Column 1 and 880 ml/min for the filter Column 2, corresponding to theoretical detention times

of 0.36 and 0.93 days respectively. The flow in Column 1 varied significantly due to a leak in the pump head, which could not be repaired during the test period, and as a result, Column 1 data could not be analyzed. Column 2 data was analyzed as shown on Figure 9.

The results revealed that the difference between measured and theoretical detention time was only 6 percent. The dye profile indicates the column was completely mixed. Figure 9 illustrates this mixing as traces of the dye appeared in the effluent within one hour of injection into the column.

Tracer Study 2

In late October, during a period in which fresh HTL was not available, tracer studies were conducted on the two columns after several months of operation to test for short circuiting. Lithium was the tracer element used for this study and was added as an impulse load. The tracer study was conducted from October 31 to November 4. The resulting tracer curves are shown in Figure 10.

Both columns showed short-circuiting or complete mixing; Column 2 somewhat more than Column 1. This may be attributed partially to a number of factors including the heating tapes on the column walls being on most of the time resulting in the influent moving up along the column walls, diffusion throughout the filter contents, mixing action of the gas produced, and absorbtion-desorbtion of the tracer to and from the biological solids. An examination of media from Column 2 after the top 1.5 meters of media was replaced with 0.61 meters of smaller media, showed more attached biomass along the column walls than in the center of the filter, supporting the theory of movement of influent up along the column walls.

PILOT PLANT OPERATION - PHASE II

Chronological Plots

In March and April, 1978, the media in the columns were reduced to 1.8 meters, and were backed flushed with air and water to wash out the accumulated solids. Mechanical equipment including feed pumps and heaters were overhauled and repaired. New insulation was installed on the filter columns to facilitate temperature control. The Muddy Creek Plant heat treatment system was shut down indefinately to correct odor problems. Therefore, arrangements were made with a local trucking firm and with the Columbus Ohio Jackson Pike Sewage Treatment Plant to insure a reliable supply of heat treatment liquor. The heat treatment liquor obtained was relatively consistent, with an average COD of 10,000 to 11,000 mg/l, except for a weaker load received toward the end of the study. As a result, it was generally possible to maintain consistent loadings and detention times.

The filters were initially seeded with 350 liters each of digesting sludge from the Milford STP on April 20. The sludge constituents are shown in Table 17. The filter effluent was recycled to bring the units to a uniform temperature. On May 1, HTL obtained from Columbus Ohio Jackson Pike

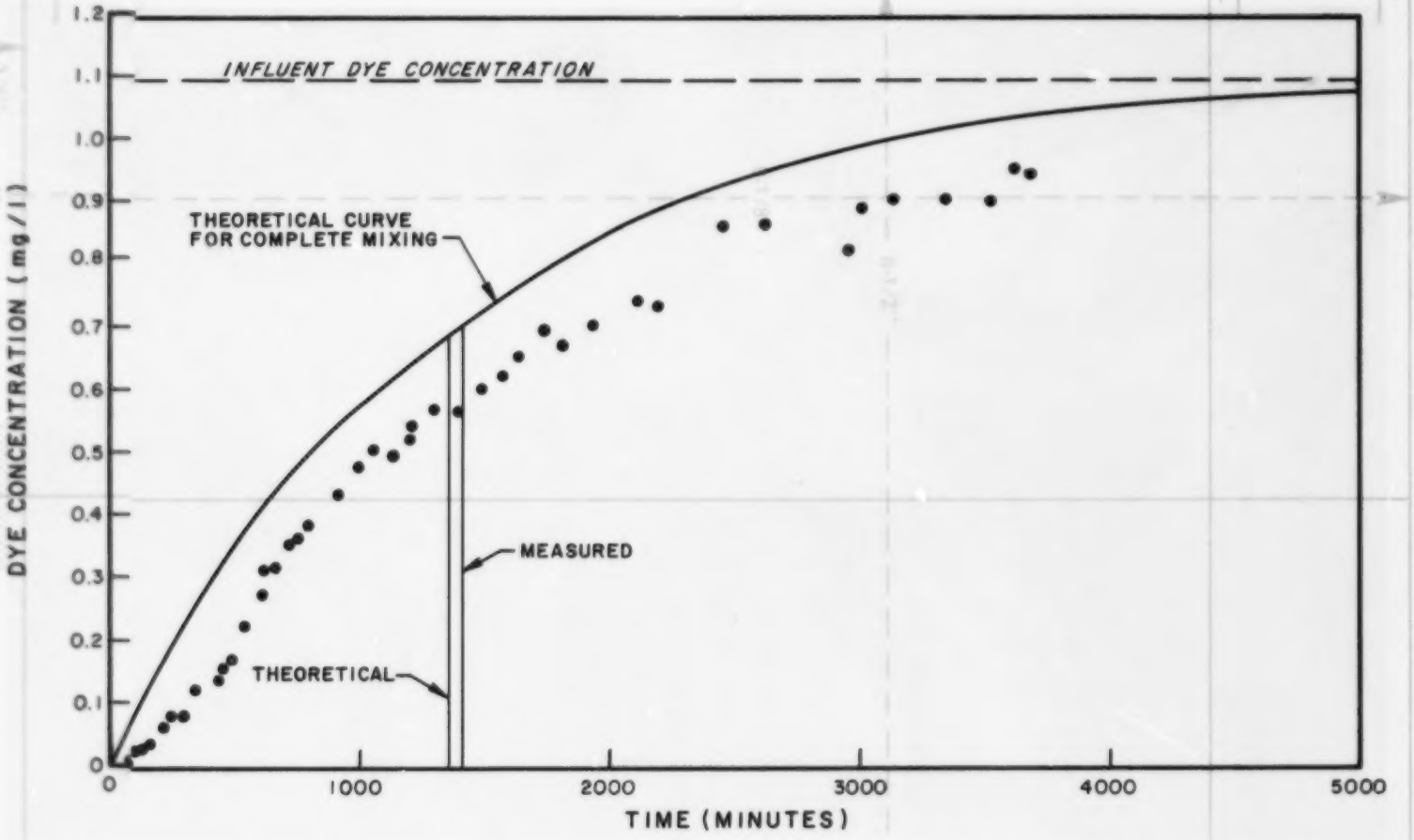


Figure 9. Dye concentration versus time.

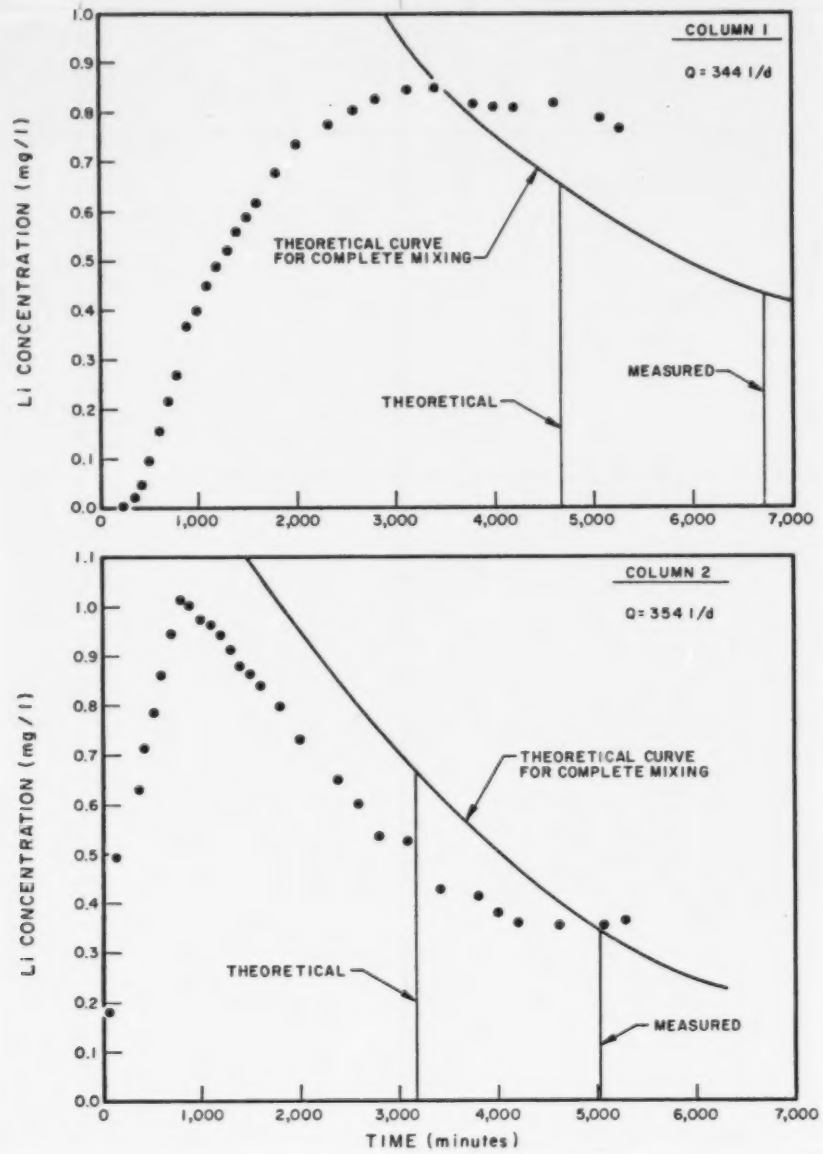


Figure 10. Tracer study-October 30, 1977

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE

TABLE 17. ANALYSIS OF SEED SLUDGE FOR THE ANAEROBIC FILTERS
Milford, Ohio Sewage Treatment Plant

	4/18/78	7/14/78
Physical Characteristics		
Total Solids (mg/l)	70,130	29,300
Total Volatile Solids %	45	-
Chemical Characteristics		
pH	7.1	6.9
Alkalinity (mg/l as $CaCO_3$)	4,080	3,920
TKN (mg/l as N)	810	680
NH_3-N (mg/l as N)	630	490
Trace Metals (mg/kg dry solids)		
Cadmium	16	32
Chromium	53	130
Copper	970	2,000
Iron	16,800	31,000
Lead	530	1,090
Manganese	150	350
Mercury	2	7
Nickel	48	110
Zinc	1,930	4,300

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cm.)
(4-76)

STP was fed to the filters. The filter loading rates were set at approximately 2.4 and 4.8 kg COD/m^3/day with detention times of approximately 3.5 and 1.8 days for Columns 1 and 2 respectively. A chronological plot of influent and effluent characteristics of the filters during Phase II is presented in Figure 11.

Analysis - Discussion of Data

Chemistry --

The carbon and nitrogen systems interact with alkalinity and thus affect the pH. Below a pH of 8.0, the hydroxide and carbonate ($CO_3^=$) concentrations are negligible and thus all carbonaceous alkalinity is in the bicarbonate form. The volatile acids produced from the degradation of the complex organic COD are almost entirely ionized as indicated in the following equation:

$$\text{Complex COD} \longrightarrow CH_3COOH \rightleftharpoons CH_3COO^- + H^+$$

Volatile acids are shown collectively as acetic acid which is the major reaction product. Lesser amounts of other carboxylic acids are also present. Degradation of the volatile acid to methane and carbon dioxide will then result in an increase in alkalinity

$$CH_3COO^- + H^+ \rightleftharpoons CH_4 + CO_2$$

In the anaerobic filter, alkalinity will be reduced initially due to volatile acid production and increase when volatile acids are converted to methane and carbon dioxide.

Volatile Acid Alkalinity = 0.633 x Volatile Acid

During startup of an anaerobic system, the pH will decrease due to volatile acid production with little conversion of volatile acids to methane and carbon dioxide.

At the same time that volatile acids are being produced, alkalinity is being produced by organic nitrogen diamination. Alkalinity from organic nitrogen is:

Org N Alkalinity = 0.5 x Org N converted to ammonia

The pH in the filter can then be calculated using the following two equations:

Bicarbonate Alk = Total Alk - V.A. Alk - Org N Alk

$pH = pK_1 - 0.056 + \log$ Bicarbonate Alk

The pH and alkalinity of the influent HTL feed were 4.9 and 600 mg/l as $CaCO_3$ respectivley. The conversion of organic nitrogen to ammonia in the filter provided some additional alkalinity, however, at the volatile acid concentrations produced, pH values of 6.0 to 6.3 were measured, somewhat outside the optimum range for methane bacteria. As a result, additional alkalinity as sodium bicarbonate was added to the raw waste on May 9,

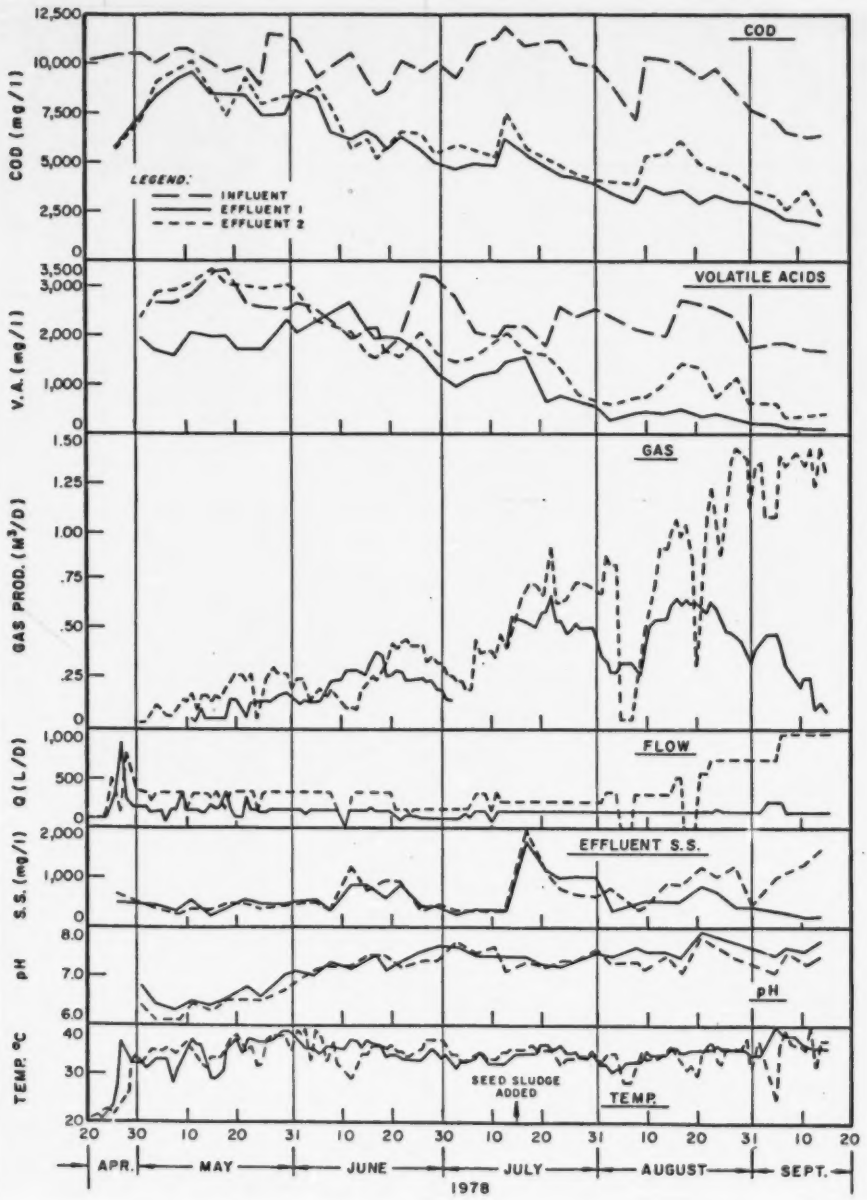


Figure II. Phase II- chronological plot.

increasing alkalinity to about 1800 mg/l, and the resulting in effluent pH values in the range of 6.5-6.7. The second load of treatment liquor from Columbus obtained on May 26 had a pH of 5.1 and alkalinity of 1500 mg/l. Sodium bicarbonate was added to increase the alkalinity to about 3200 mg/l. Filter effluent pH values following the introduction of the new feed moved up to approximately 7.0. During June, effluent COD and volatile acids gradually decreased and it was not necessary to add additional buffering chemicals to subsequent loads of HTL.

Operation --

Filter performance improved through June as the methane forming organism population increased slowly. This slow increase was apparently caused in part by the washout of organisms, indicated by the high effluent suspended solids. The operating conditions were steady for the first three weeks of June. On two days in June, flow was halted for 24 hours in an attempt to increase the retention of organisms. The brief interruptions helped, but only for a short period, after which high solids again washed out in the effluent. Flow rates to both columns were cut in half on June 21 to decrease the solids losses. Effluent solids concentrations dropped slowly thereafter, and effluent COD continued to decrease in both columns. Gas production steadily increased in mid June but started to drop off with the reduction in COD loading.

The filters continued to show a slow improvement, thus on July 14, 166 liters of digesting sludge from the Milford STP was added to each filter to accelerate acclimation. Gas production rose immediately, however, a higher solids level was noted in the effluents. This sludge addition helped increase COD removal and reduce volatile acid concentration to relatively low levels by early August. The loading rate was increased in several increments from August 1 to September 20 from 3.0 kg COD/m^3/d to about 9.5 kg COD/m^3/d in Column 2, while Column 1 was operated at a constant loading of about 2.5 kg COD/m^3/d. During this period, gas production increased concurrent with the loading increases. Although substantial reduction in volatile acids and COD occurred, the effluent concentration continued to exhibit a downward trend in both filters, indicating continual, gradual buildup, and retention of methanogenic organisms in the filters, right through to the end of the study period.

As can be seen in Figure 11, gas production more or less reflected the influent flow and COD levels. On two occasions in August when flow was interrupted for several days to Column 2, gas production dropped off, then upon resumption of flow increased back to previous production levels. Figure 12 illustrates the relationship between gas production in cubic meters per day and the COD loading, during the study. The higher removal, thus greater gas production for a given loading in Column 1, is reflected in the steeper slope of the data points. No curves are drawn through the data since as noted above, the systems were continuing to increase removals throughout the study, thus steady state conditions were not fully established at any one loading condition.

Tables 18 and 19 present 10 day average operational results for Column 1 and 2, respectively, from June through the end of the study. The gradual

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE

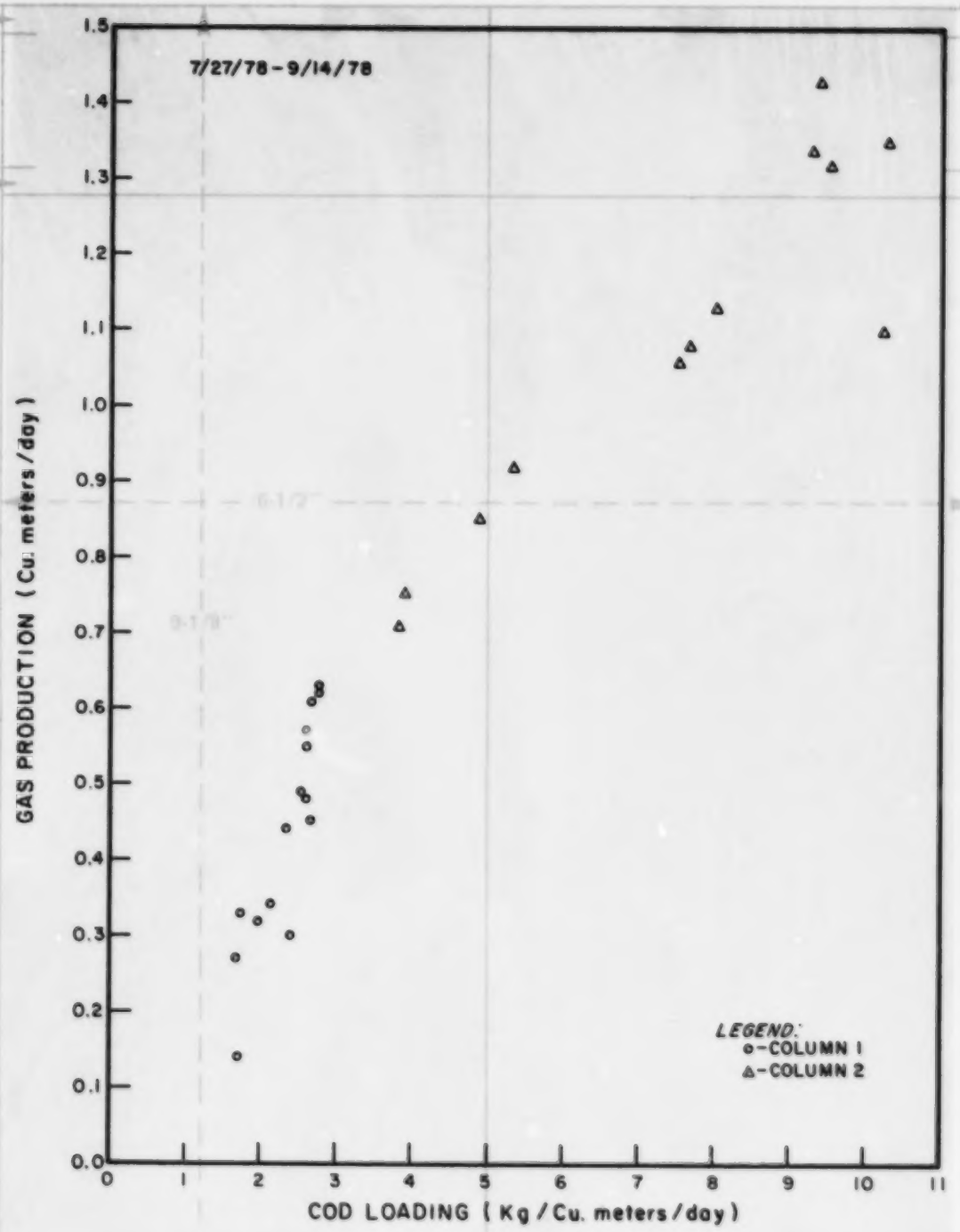


Figure 12. Gas production versus COD loading.

BEGIN LAST LINE OF TEXT
3/8"
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

EPA-287 (Cin.)
(4-76)

TABLE 18. COLUMN #1 - PHASE II
10 DAY AVERAGE OPERATION

Date 1978	Day #	Flow L/d	Detention Time Days	Loading Rate kg COD/m^3/d	$\frac{m^3 gas}{kg\ COD_R}$	Avg. Temp. °C	$\frac{ft^3}{\#COD_R}$	COD§ Removed %	BOD§ Removed %
6/1-10	42-51	174	3.90	2.59	.48	35.5	7.7	21	-
6/11-20	52-61	165	4.12	2.23	.62	35.5	9.9	33	-
6/21-30	62-71	107	6.36	1.56	.48	34.0	7.7	49	(60)
7/1-10	72-81	124	5.48	1.84	*	33.0		53	66
7/11-20	82-91	184	3.70	3.07	.49	34.0	7.8	52	-
7/21-31	92-102	179	3.80	2.76	.49	34.0	7.8	59	(67)
8/1-10	103-112	178	3.82	2.37	.33	32.0	5.3	63	83
8/11-20	113-122	180	3.78	2.68	.52	34.0	8.3	65	77
8/21-31	123-133	190	3.58	2.58	.54	35.0	8.6	66	80
9/1-10	134-143	203	3.35	2.13	.41	37.0	6.6	64	86
9/11-15	144-	180	3.78	1.69	.22	35.5	3.5	68	85

§ $\frac{\text{Total Influent - Filtered Effluent}}{\text{Total Influent}}$ x 100%

Adjusted values in ( ) based on evaluation of data.

* Meter not operating.

TABLE 19. COLUMN #2 - PHASE II
10 DAY AVERAGE OPERATION

Date 1978	Day #	Flow L/d	Detention Time Days	Loading Rate kg $COD/m^3/d$	$\frac{m^3\ Gas}{kg\ COD_R}$	Avg. Temp. °C	$\frac{ft^3\ Gas}{\#\ COD_R}$	COD[§] Removed %	BOD[§] Removed %
6/1-10	42-51	350	1.94	5.21	.31	36	5.0	17	-
6/11-20	52-61	284	2.39	3.85	.24	35	3.8	39	(56)
6/21-30	62-71	210	3.24	3.06	.51	35	8.2	38	(45)
7/1-10	72-81	170	4.00	2.53	.42	34	6.7	43	57
7/11-20	82-91	268	2.54	4.47	.41	35	6.6	47	-
7/21-31	92-102	263	2.59	4.06	.46	34	7.4	58	(56)
8/1-10	103-112	245	2.78	3.25	.39	32	6.2	52	74
8/11-20	113-122	272	2.50	4.05	.57	33	9.1	(47)	(74)
8/23-9/6	125-139	717	0.95	8.75	.40	35	6.4	52	66
9/7-15	140-146	988	0.69	9.39	.39	37	6.2	55	78

[§] $\frac{\text{Total Influent - Filtered Effluent}}{\text{Total Influent}} \times 100\%$

Adjusted values shown in ( ) based on evaluation of data.

increase in COD and BOD removals can be noted as shown in Figure 13. Column 1 COD and BOD removals were essentially constant during the last month of the study and were significantly higher than the results obtained in Column 2, operated at increasingly higher loadings and lower detention times. Percent removals were calculated based on total influent and filtered effluent to eliminate the variability of effluent suspended solids on the data. The relatively high effluent solids would, however, contribute to effluent BOD and COD resulting in somewhat lower overall removals. As shown in Figure 20, one mg/l effluent solids would contribute approximately 1.5 mg/l COD.

Volumetric Loading-Removal Relationships

The relationships of BOD and COD removal, hydraulic detention time and loading rate are shown in Figures 14 and 15. The data shown are for loading conditions after 7/31/78, when the filters were at more steady state operating conditions.

The data show only a slight decline in removal based on increasing loading rate or detention time in the range studied. As noted previously, the effluent concentrations were gradually decreasing throughout the study and it is probable that complete steady state conditions were not established. The gradual process of retention of methanogenic organisms through attachment to the filter media and in settleable solids within the void volume between media was continuing.

Whether or not the specific media used, and the depth used, with the combination of influent concentration and flow rates would permit build up of higher concentrations of methane formers, thus resulting in higher removals at the loadings studied or at substantially higher loadings was not determinable within the time frame of these studies. Thus, based on the data obtained, a relatively conservative design loading and detention would be derived. The results achieved on this waste in the laboratory units is discussed later in this section and are taken into consideration when the proposed design loading is selected.

The primary gases produced in anaerobic treatment are carbon dioxide and methane. Table 20 presents the analysis performed during Phase II on gas samples from the filters. The small amount of oxygen measured was attributed to some leakage of air into the sample bag and in the test apparatus. Initially, with conversion of the organics to volatile acids and low gas formation, the percentage of CO_2 in the gas was relatively high. The methane content of the gas increased as the filters became acclimated. Column 1 had slightly higher methane content during most of the study compared to Column 2, indicative of the more steady state operation and loading of Column 1. Both filters were producing gas containing about 65 to 70% methane by the end of the study.

A correlation of gas production versus soluble organic removal is shown in Figure 16. An average value of 0.5 m^3 gas/kg soluble COD_R (removed) is indicated. This value is consistent with typical gas production, COD correlations found in the literature and in previous studies. Figure 17 shows total gas produced and the methane and carbon dioxide constituents of the gas sam-

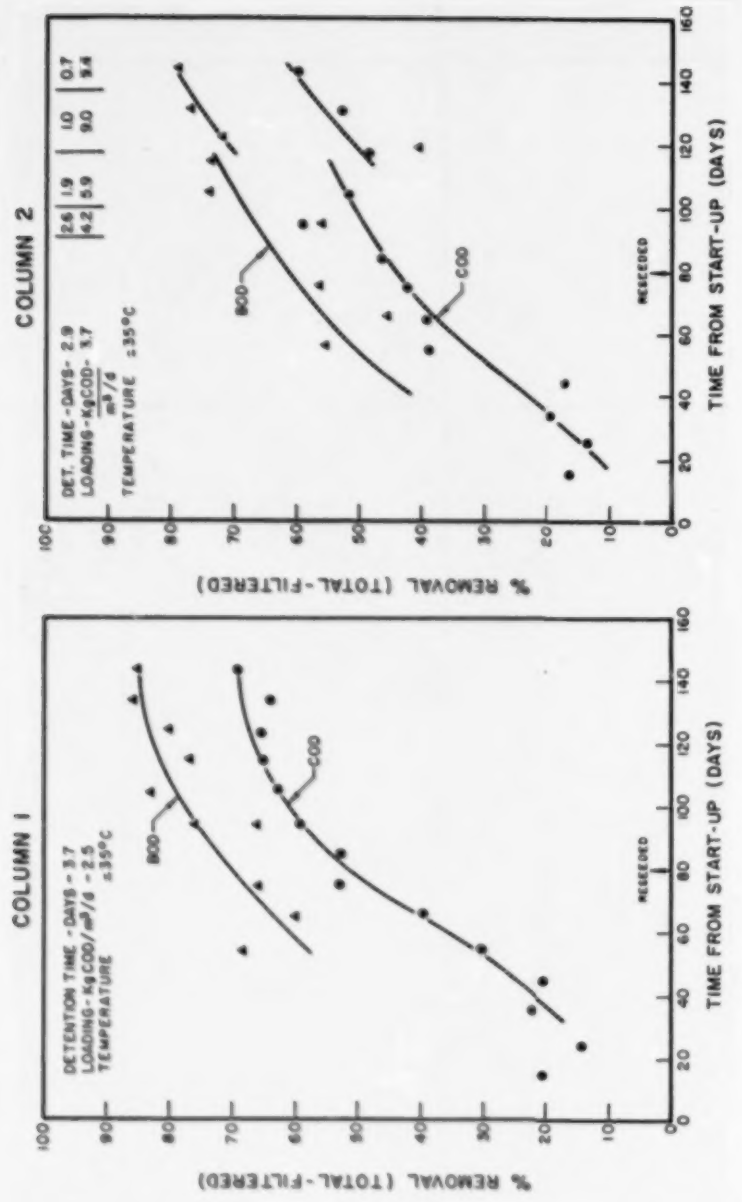


Figure 13. BOD and COD removal.

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD, BEGIN SECTIONS HERE

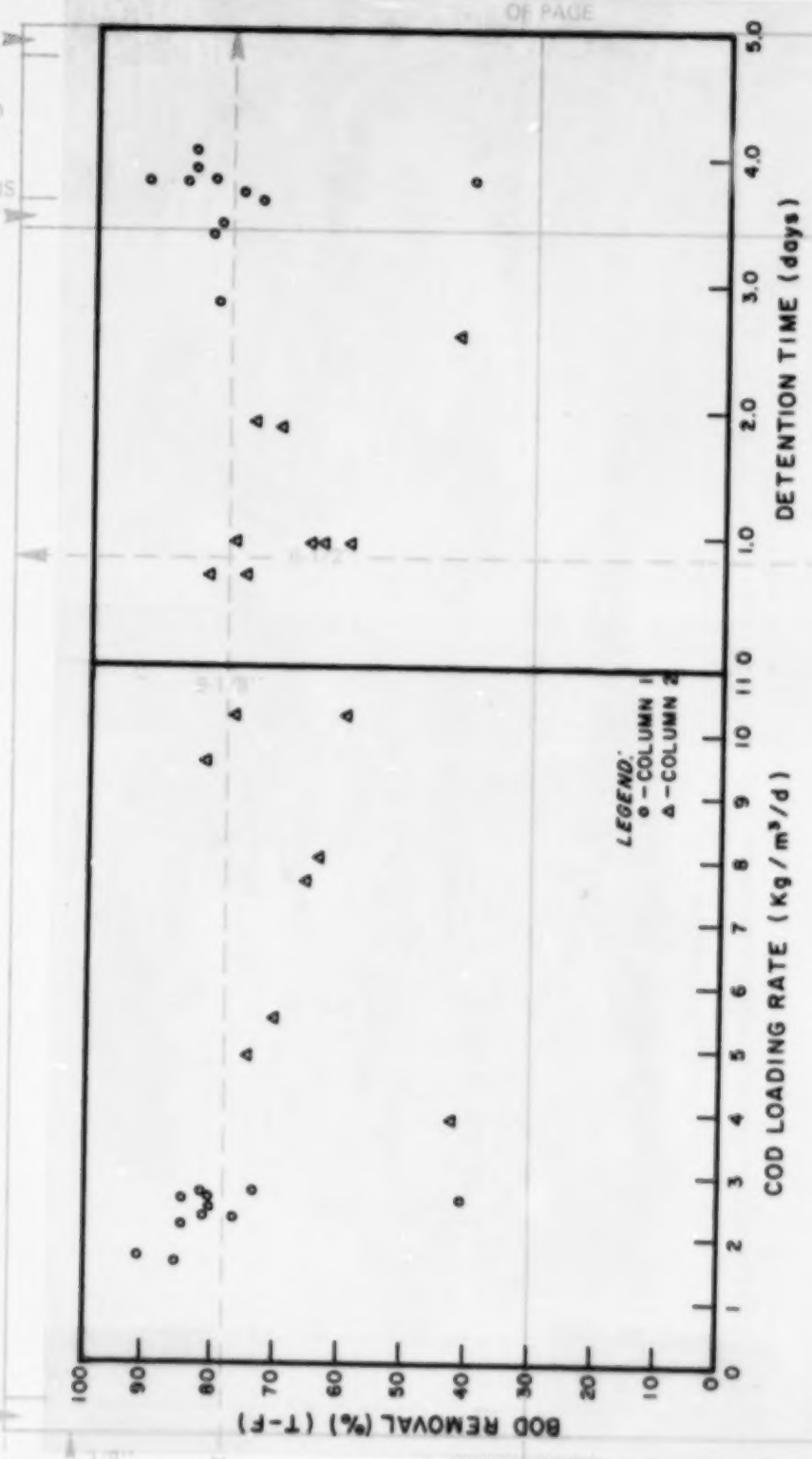


Figure 14. BOD removal versus loading rate and detention time.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

EPA-287 (Cin.)
(4-76)

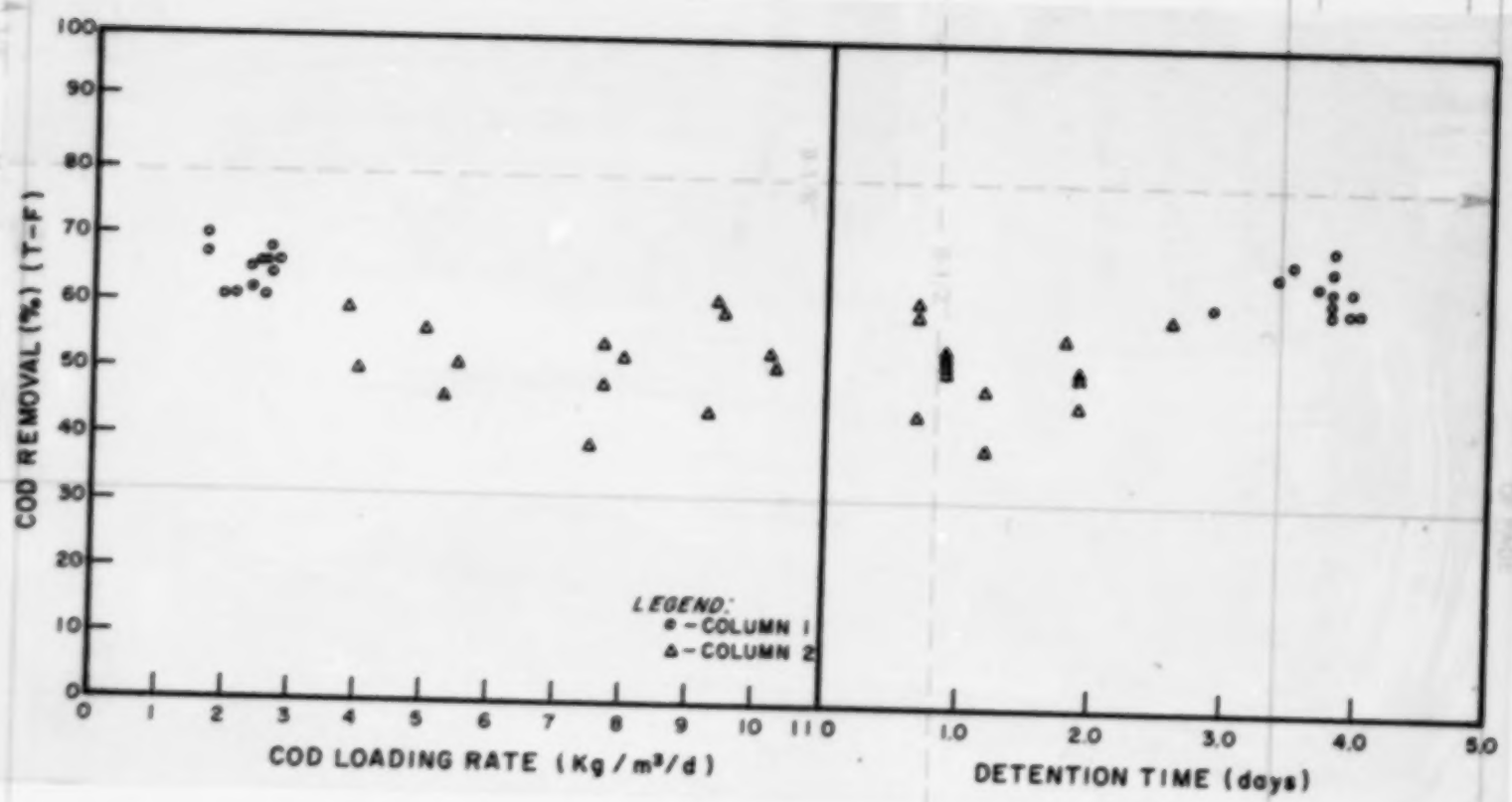


Figure 15. COD removal versus loading rate and detention time.

TABLE 20. GAS COMPOSITION

Date	Column 1				Column 2			
1978	CO_2 %	O_2 %	CH_4 %	Other	CO_2 %	O_2 %	CH_4 %	Other
5/29	38	5	33	24	43	8	31	18
6/17	33	5	43	19	27	5	47	21
7/16	27	4	54	15	28	7	57	8
7/21	29	1	70	0	30	1	59	10
8/13	25	3	68	4	27	4	56	13
8/20	25	2	69	4	23	3	64	10
8/26	24	1	71	4	21	3	65	11
9/1	21	3	69	7	22	2	72	4
9/9	25	-	-	-	22	-	-	-
9/14	26	-	-	-	22	-	-	-

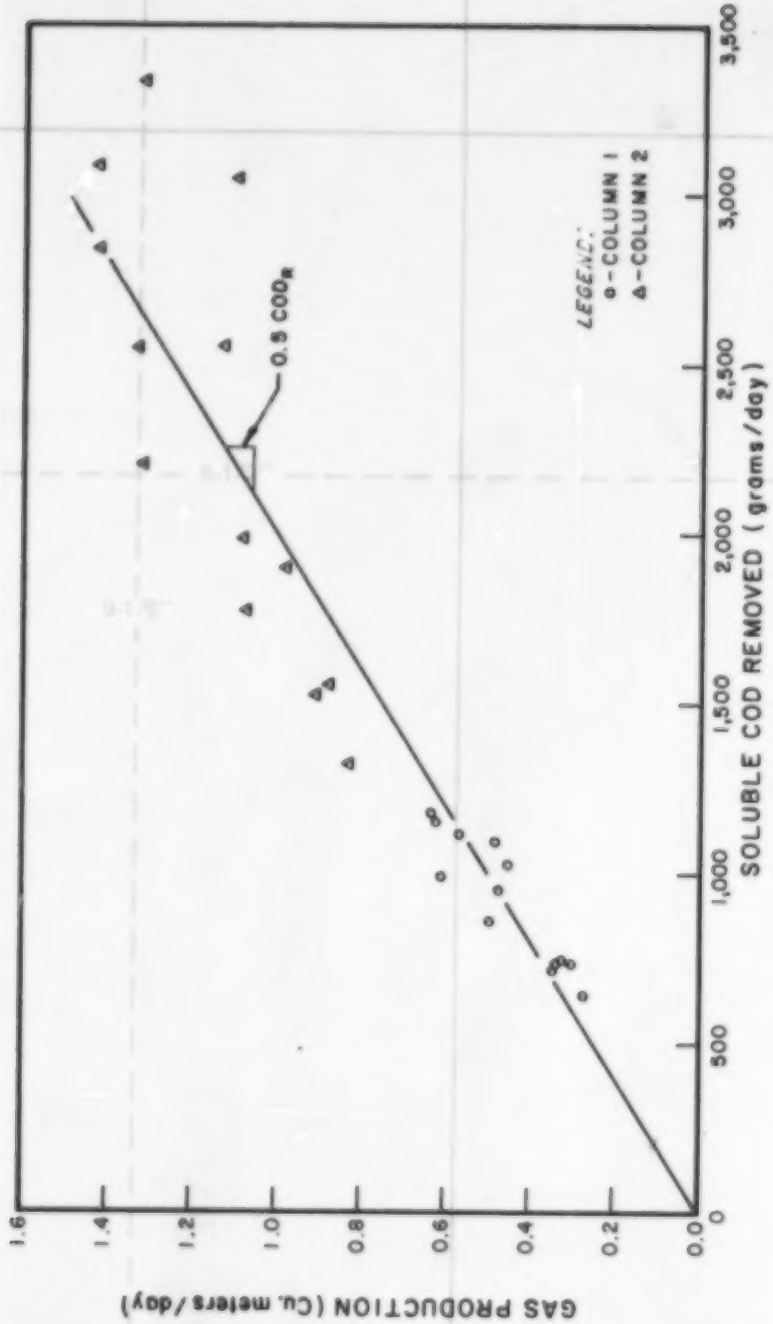


Figure 16. Gas production versus soluble COD removed.

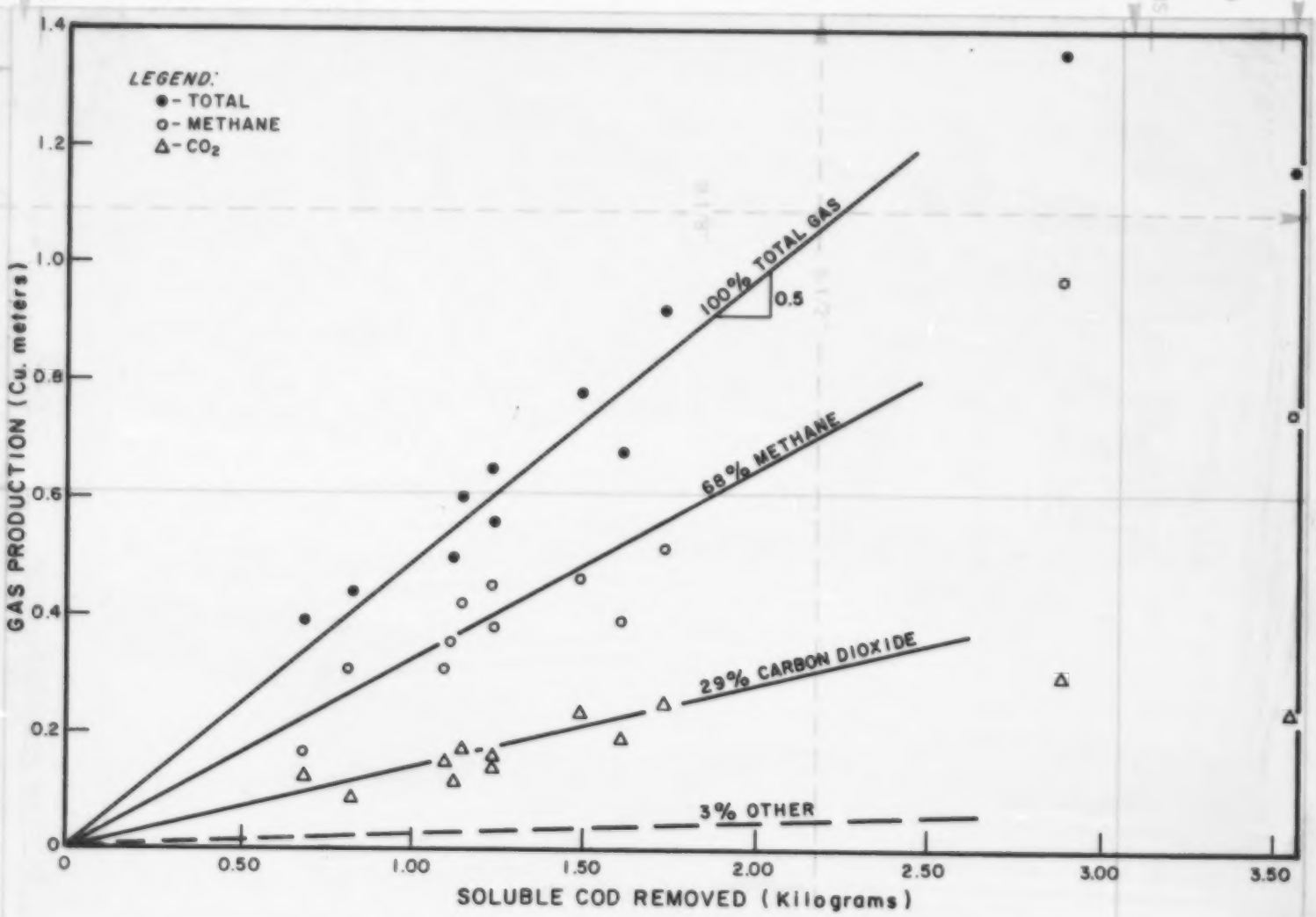


Figure 17. Gas composition versus soluble COD removed.

ples measured, versus the soluble COD removed. Gas production by biological solids decay in the filter was relatively small, as shown during those days when no influent was fed to the column. The recycle degradation study in Phase I, 8/27 to 9/2/77, showed that the gas produced by solids decay was less than 2% of the total gas production.

BOD - COD Relationship

The COD-BOD relationship for the influent and effluents during Phase II is displayed in Figure 18. A non-biodegradable COD of 1200 mg/1 was calculated. The COD to BOD_5 ratio was 2.1 to 1.0. Table 21 and Figure 19 show the results of a long term BOD test run on the heat treatment liquor and treated effluent.

A soluble non-biodegradable COD in the order of 1100 mg/1 is indicated by the data in Table 21. Between Figure 18 and Table 21, an average non-biodegradable COD fraction in the heat treatment liquor samples studied, of 1100 mg/1 $\pm$ 200 mg/1 is indicated.

COD - Suspended Solids Relationship

The insoluble COD that was fed to the units was a fraction of the total COD. The COD of the solids were computed by plotting the difference of the total and filtered COD versus the suspended solids of the influent and effluent samples. This plot is shown in Figure 20. The data is quite scattered and variable. The COD of the influent suspended solids averaged 2.0 times the solids concentration and the COD of the effluent solids averaged 1.5 times the effluent solids concentration.

SPECIAL STUDIES

Hydraulic Tracer Studies

Tracer studies were conducted on the two pilot anaerobic filters from May 31 to June 8. The tracer used was lithium chloride which was injected into the columns through the recycle lines. Effluent samples were taken every four hours. Figure 21 displays the lithium concentrations and theoretical curves representing completely mixed reactors. The columns' hydraulic characteristics were partially disguised by the adsorption of some of the lithium into the biomass and leaching back into the liquid. Table 22 summarizes the data from the tracer study.

TABLE 22. HYDRAULIC TRACER STUDY
PERFORMED 5/31 - 6/8/78

	Column 1	Column 2
Average Flow (l/d)	173	360
Empty Bed Volume (liters)	850	850
Theoretical Detention Time (days)	4.9	2.4
Measured Detention Time (days)	5.2	2.2

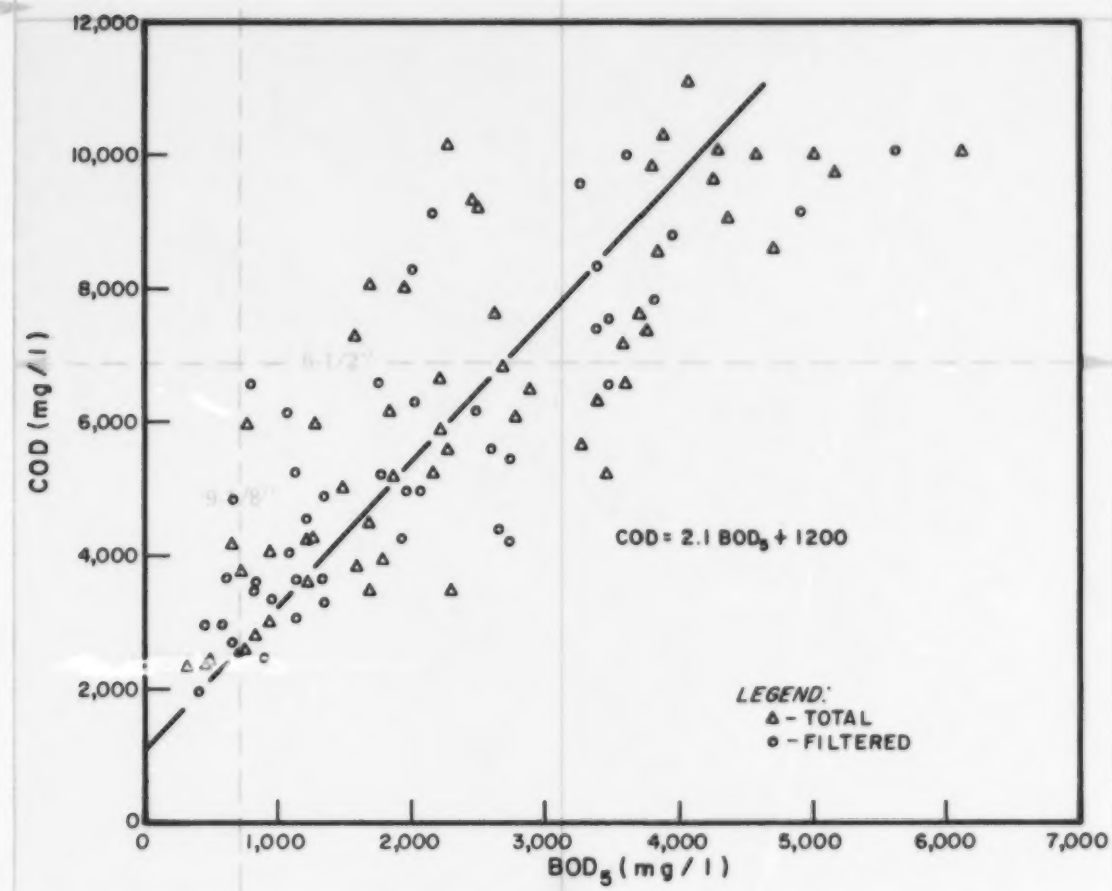


Figure 18. Phase II - COD versus BOD.

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE

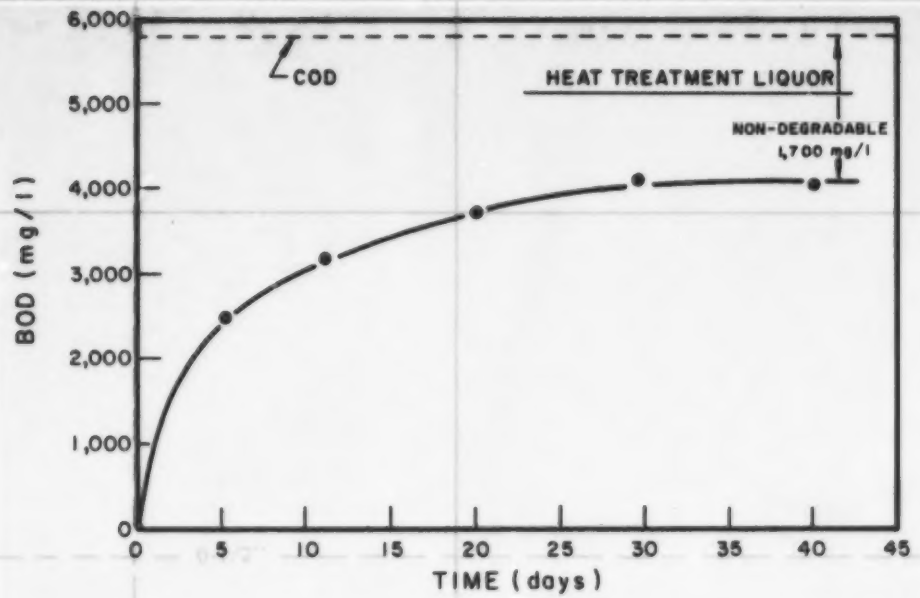
TABLE 21. LONG TERM CARBONACEOUS BOD*
ON HEAT TREATMENT LIQUOR

Day	Influent BOD		Effluent BOD	
	Total mg/l	Filtered mg/l	Total mg/l	Filtered mg/l
5	2470	2350	410	260
11	3160	3100	610	390
20	3710	3560	700	410
29	4100	4020	860	600
40	4010	3750	870	570
COD(Reflux)	5800	5170	2020	1610
COD-BOD_u	1745	1285	1150	1040
COD/BOD_5	2.3	2.2	4.9	6.2
BOD_u/BOD_5	1.6	1.7	2.2	2.2

* TCMP added to inhibit nitrification

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-257 (Cin.)
(4-76)



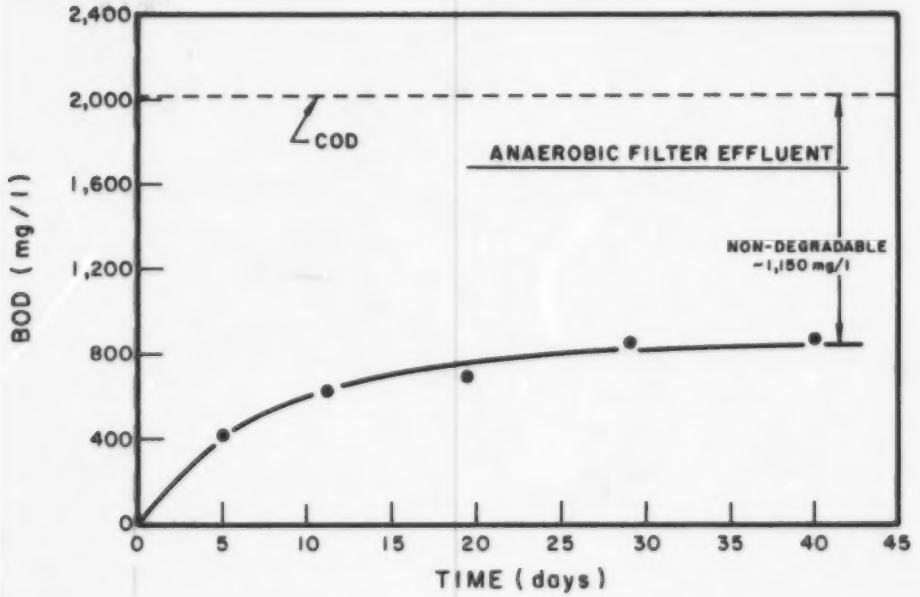


Figure 19. Long-term BOD tests.

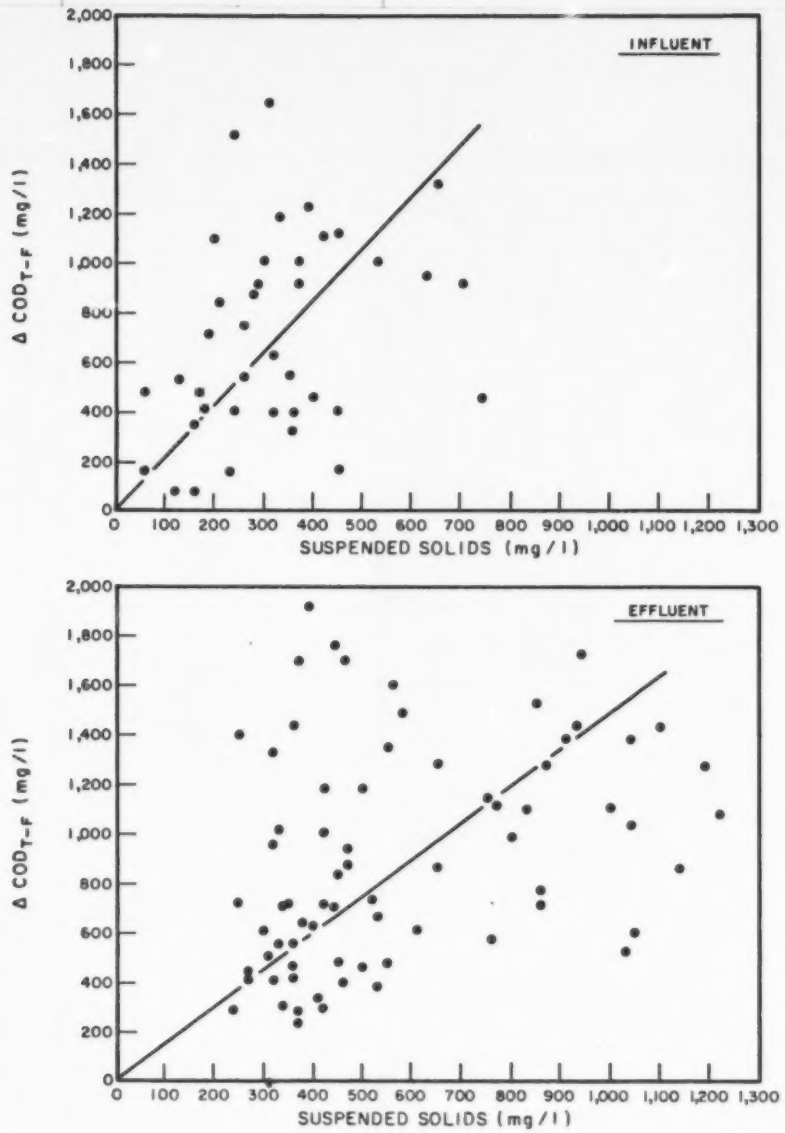


Figure 20. COD of suspended solids.

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD. BEGIN SECTIONS HERE

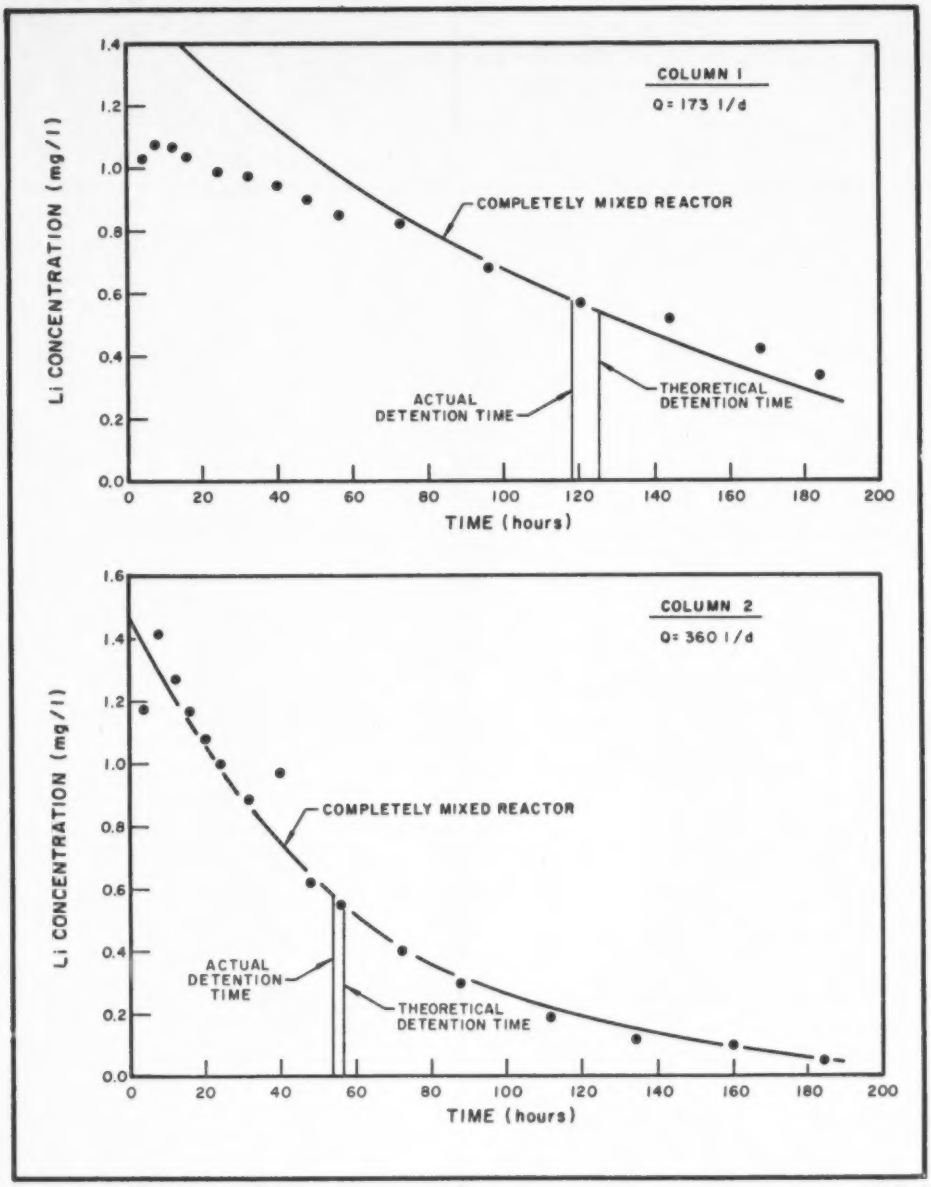


Figure 21. Tracer study — May 31 - June 8, 1978.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA. OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

EPA-287 (Cin.)
(4-76)

At 173 1/day, Column 1 had a theoretical clean filter detention time of 4.9 days. The measured detention time by the tracer was 5.2 days. At 360 1/day, Column 2 had a theoretical clean filter detention time of 2.4 days compared to the measured detention time of 2.2 days.

The hydraulic behavior of both Columns were closer to a completely mixed reactor than a plug flow system. The mixing could be attributed to the rising gas bubbles and thermal gradients in the column.

Depth Studies

Depth studies were conducted four times during Phase II. Tables 23 and 24 summarize the results, which are graphically shown in Figures 22 and 23. Samples were taken from the influent, Tap #1, 2, 3, and 5 which were located 0.3, 0.6, 0.9, and 1.5 meters from the bottom of the column respectively. The effluent was 2.3 meters above the bottom of the column.

Column 1 tap studies show the evolution of the anerobic filter with time. The first tap study occurred 60 days after the columns were seeded. Both columns showed no removal with depth, and high suspended solids in the first two taps. On July 17, the second tap study was performed three days after the columns were reseeded with sludge. Both columns had higher solids levels but again no organic removal with depth was observed. Apparently all the removal was taking place in the first 0.3 meter of the column or uniformly throughout the column due to mixing and dispersion.

The third tap study on the 1st of August showed lower total suspended solids but better organic removals in the filters. The columns showed some decrease of volatile acids with depth, however, most removal occurred in the first 0.3 meters. The fourth tap study was performed on September 13, and showed a marked difference. The suspended solids level in Column 1 had dropped significantly from the previous study. There was a decrease in volatile acids between tap one and three. At the flow rate applied, much of the suspended, untrapped solids, were washed out of Column 2. Volatile acid levels were uniform with depth. Apparently, the attached growth on the media contained the organisms responsible for the reduction of volatile acids and the methane formers. The relatively low and uniform volatile acids concentration throughout the column indicated that removal was taking place throughout the columns.

Attached and Suspended Growth

An examination of the filter media to determine the mass of attached solids at different depths was conducted at the end of the study. The filter void volume was determined by measuring the volume of liquid drained from the column at each tap. The liquid volume plus the volume of the plastic media subtracted from the measurement of volume of the column, provided an estimate of the attached growth volume. Suspended solids from each tap were measured to determine unattached solids in each section. Media was removed from the columns after the columns were drained. The attached solids were scraped from a number of typical media from each depth into a known volume of water. Table 25 contains the results of these tests.

TABLE 23. TAP STUDY RESULTS

6/20/78

Tap #	COD_F	Vol. Acids[§] as acetic acid	Alkalinity[§] as $CaCO_3$	Sus. Solids mg/l
Influent	7713	1968	4940	632
		Column 1		
1	6453	1920	4700	40,920
2	6532	2040	4780	15,700
3	5745	1944	4880	2,840
5	6296	1968	4580	1,250
Effluent	6320	1968	4840	873
		Column 2		
1	5273	1248	4780	52,160
2	5037	1776	4400	27,320
3	6611	1992	3940	1,400
5	6060	1840	3880	1,760
Effluent	6560	1560	4460	933
		7/17/78		
Influent	10,445	2184	1620	735
		Column 1		
1	4531	-	3825	63,280
2	4838	-	3760	41,160
3	4454	-	3640	23,960
5	4992	-	3200	5,540
Effluent	5376	1584		1,730
		Column 2		
1	5222	-	3775	59,480
2	5069	-	3500	46,060
3	5453	-	3120	14,000
5	4838	-	3040	5,580
Effluent	5606	1680		2,120

pH - 7.1 to 7.4

Values in mg/l

Note - Columns contain 1.8m of media, 0.5 meters of liquid volume above the media to the effluent take off. 57 l of digesting sludge was added to each column on 7/14/78.

[§]Unfiltered samples

TABLE 24. TAP STUDY RESULTS

Tap #	Vol. Acids† as Acetic Acid	Alkalinity† as $CaCO_3$ mg/l	Total Solids* mg/l
		8/31/78	
Influent	1752	1980	-
		Column #1	
1	-	3900§	51,235
2	576	-	30,680
3	216	2980	3,515
5	96	3120	9,545
Effluent	216	3060	3,540
		Column #2	
1	840	3905§	45,315
2	696	-	14,155
3	648	2860	3,930
5	672	2960	4,895
Effluent	624	2560	3,284
		9/13/78	
Influent	1704	1660	3,524
		Column #1	
1	432	2660	25,016
2	456	2360	9,504
3	144	2360	2,452
5	120	2420	3,124
Effluent	120	2320	2,336
		Column #2	
1	456	2100	3,764
2	408	2120	3,496
3	456	2180	3,472
5	432	2220	3,560
Effluent	408	2120	3,004

pH - 7.3 - 7.6

* Total dissolved solids = approximately 2450 mg/l

§ Affected by high solids concentration

† Unfiltered Samples

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD. BEGIN SECTIONS HERE

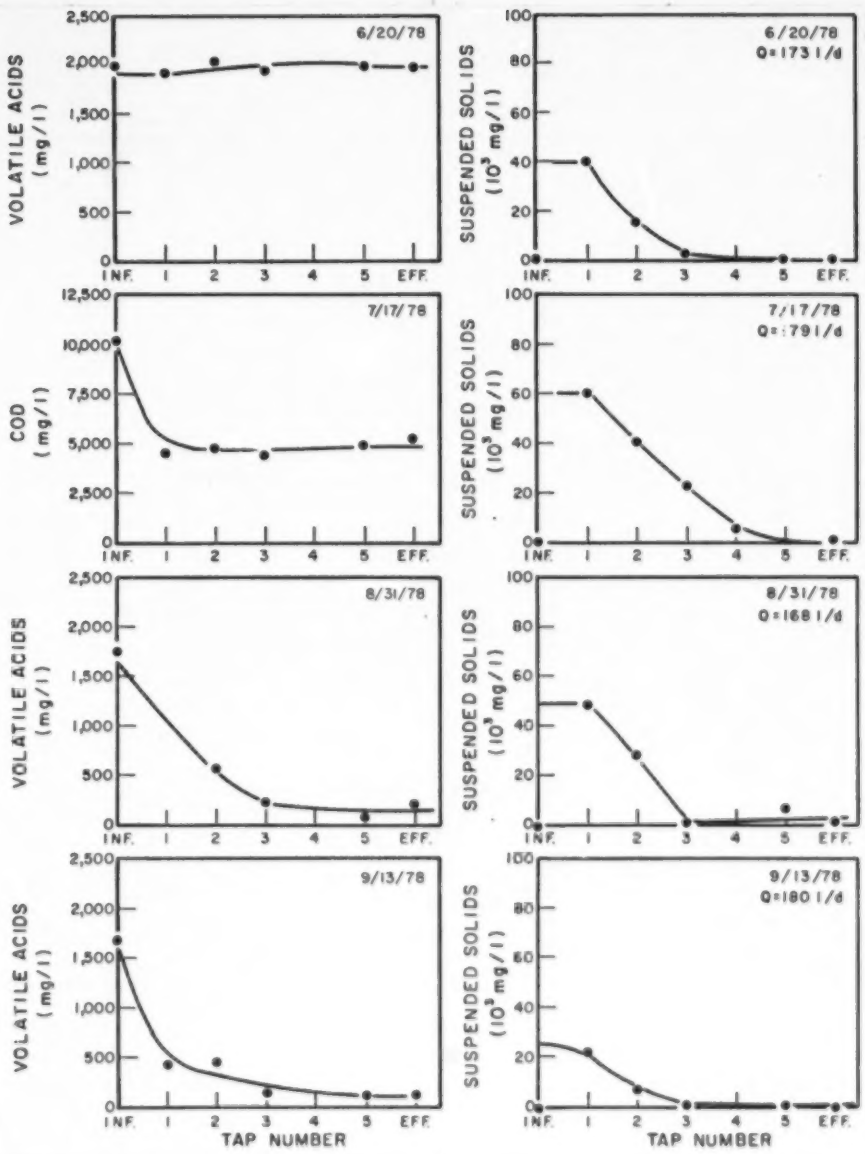


Figure 22. Depth study – column No. I Phase II.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

EPA-287 (Cin.) (4-76)

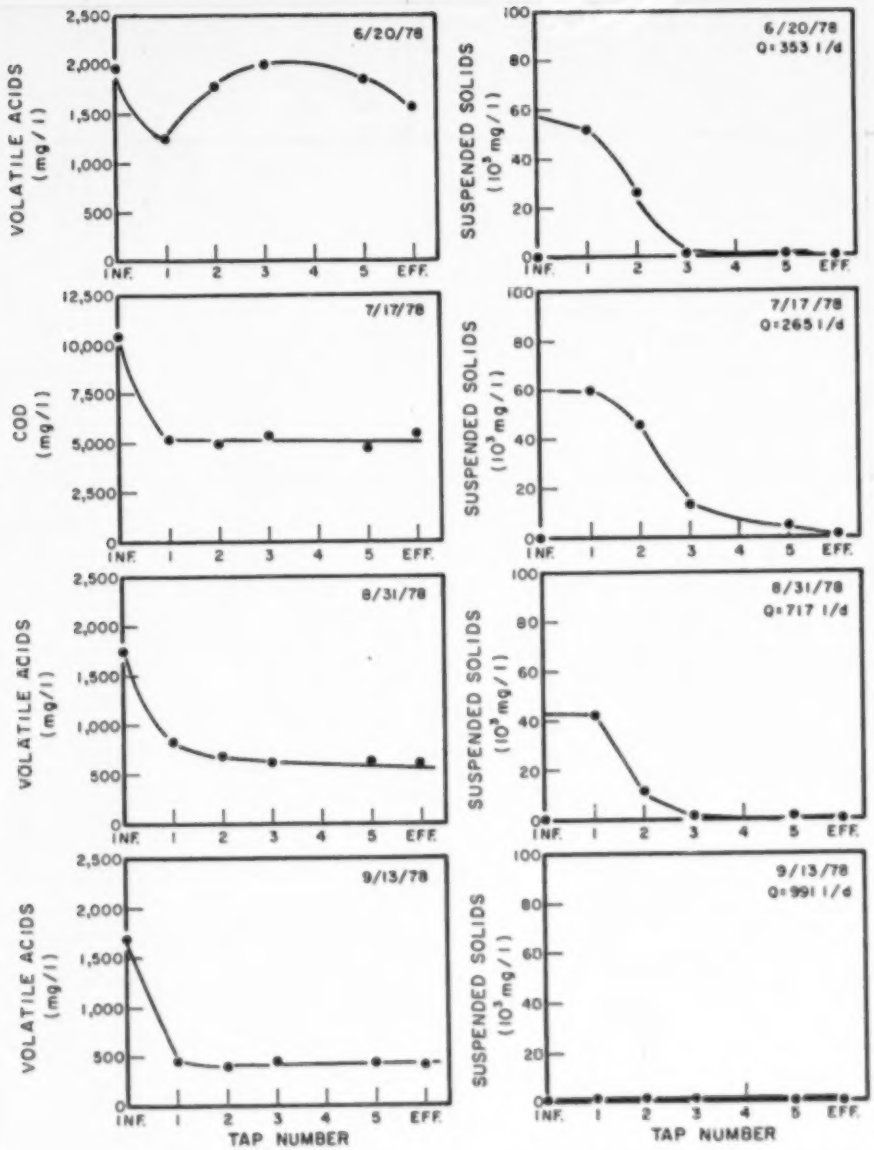


Figure 23. Depth study – column No. 2 Phase II.

TABLE 25. SPECIAL STUDIES - 9/17/78
FILTER ATTACHED AND SUSPENDED SOLIDS DATA

Column 1 Tap§	Column Height Meters	Attached g / m^2 of media	Attached g / m^3 of column	Attached g	SS g	Total g	Total kg* / m^3	Drained Volume Liters	Pct.* Voids
5	1.2-1.5	69	7020	790	27	817	7.2		
4	0.9-1.2	62	7310	710	33	743	6.6	94	83
3	0.6-0.9	72	7320	830	14	844	7.5	98	85
2	0.3-0.6	73	7220	820	970	1790	15.8	66	58
1	0.0-0.3	170	17290	1950	3870	5820	51.5	78	69

Loading Rate = 2.5 ± kg COD/m^3/d
Flow = 180 ± 1/day

Column 1 Tap§	Column Meters Height	Attached g / m^2 of media	Attached g / m^3 of column	Attached g	SS g	Total g	Total kg* / m^3	Drained Volume Liters	Pct.* Voids
5	1.2-1.5	96	9760	1100	73	1173	10.4		
4	0.9-1.2	97	9860	1110	67	1177	10.4	92	81
3	0.6-0.9	95	9660	1090	39	1129	10.0	88	78
2	0.3-0.6	61	6200	700	33	733	6.5	90	80
1	0.0-0.3	66	6710	760	84	844	7.5	86	76

Loading Rate up to 9.5 kg COD/m^3/d
Flow up to 995 1/d

* Empty bed volume basis. Each tap is 113L

§ Taps are at .3 meter intervals, Tap 1 is .15 meter from the bottom, media height 1.8 meters

Note: Example calculation can be found in Appendix C

Column 1 showed a high amount of solids concentrated in the lower 0.3 meter. The amount of attached growth was greater than the suspended solids in the upper depths, however, at taps 1 and 2, there were more suspended solids than attached. The void volume of the column was less in the lower portions because of the amount of attached growth. The average solids concentration in Column 1 was calculated based on the clean bed volume, including media (95% porosity), to be 15.2 kg/m^3.

Column 2 in contrast to Column 1, had a fairly uniform suspended solids concentration, with somewhat more attached growth in the filter upper sections. Void volumes were approximately 80% in Column 2. The average solids concentration in Column 2 was 8.7 kg/m^3, about 60 percent that determined for Column 1.

The lower suspended solids concentration in Column 2 was attributed to greater turbulence induced by the higher gas production and flow rates causing a washout of suspended solids. In Column 2 most, if not all, of the organic removal was accomplished by the attached or trapped growth. In Column 1 the organic removal was probably accomplished by the combined attached and suspended solids.

Based on the solids measured in the columns at the end of the study, the range of COD loadings applied to the pilot columns in terms of kg of COD per kg of solids in the filter per day were calculated and are:

	Range of COD Loadings	
	Solids Basis kg/kg/d	Volumetric Basis kg/m^3/d
Filter Column 1	0.081 to 0.13	1.5 to 2.5
Filter Column 2	0.42 to 0.95	4.0 to 9.0

The solids concentration in the filters varied during the study, as shown by the tap studies, thus these values are an approximation of the loading range applied at the various loading conditions studied.

LABORATORY ANAEROBIC FILTER - RESULTS

Start-up

A 5 cm diameter lab bench scale laboratory filter containing 1.6 cm plastic media rings was started up in November, 1977 at Hydroscience's Westwood laboratory. The unit received HTL feed from Cincinnati under closely controlled conditions in order to compare lab results with the full scale pilot plant, and to use the lab unit to study loading conditions prior to applying them to the field pilot units.

The unit was seeded with Bergen County, New Jersey STP digesting sludge and HTL feed was started. The unit was initially loaded at 4.0 kg COD/m^3/d and the detention time was 1.4 days. Significant gas production did not occur until early January due to several delays and start-up problems. Dur-

ing the acclimation period, it was necessary to adjust the pH to 7 with sodium bicarbonate providing an alkalinity of 2000 mg/1. During January and February, the filter continued to acclimate to the HTL at a loading rate of 4.0 kg/m^3 COD/day. Approximately 50% removal of COD was being achieved at the time. During March, a synthetic protein-carbohydrate feed was used due to exhaustion of the HTL supply. The filter readily acclimated to the synthetic feed and by the end of March, COD removal was up to 85% at a loading of 7.0 kg COD/m^3/d and detention time of about 0.7 days. Gas production was up to 110 1/d.

Chronological Data

A supply of HTL was shipped from Columbus and was fed to the filter on April 7. Chronological plots of the filter parameters and performance are shown in Figure 24. The loading rate averaged 4.2 kg COD/m^3/d for the month of April with an average COD removal of 72% and BOD removal of 88%. The effluent filtered COD stayed relatively level at the 1600 mg/1 $\pm$ 200 mg/1 range. Volatile acids in the effluent were averaging about 100 mg/1.

The loading rate to the filter was increased in early May to 6.7 kg COD/m^3/d. The filtered effluent COD remained around 1600 mg/1. The filter's reaction to increased loading was minimal, and the filtered effluent COD stayed below 2000 mg/1 through May. The gas production mirrored the increases and decreases in COD loading rate.

A fresh supply of HTL arrived at Hydroscience and was fed starting on June 9. The higher concentration resulted in increasing the loading rate to 11.0 kg COD/m^3/d, the detention time remained about 18 hours. The effluent COD rose to 4000 mg/1 but decreased to about 2500 mg/1 by the end of June. COD removal varied from 54 to 79% and BOD removal from 83 to 94%. Gas production increased at the end of June.

The pH in the system rose to 8.0. The total ammonia concentration was 740 mg/1, and at pH 8.0 the free ammonia concentration was about 80 mg/1. Values as low as 25-40 mg/1 had been reported as toxic to anaerobic systems. Hydrochloric acid was used to decrease the alkalinity and pH in the feed to the column resulting in a pH of 7.4-7.6 in early July, thus decreasing the calculated unionized ammonia to about 25 mg/1. Gas production was increasing at the end of June and stayed at these levels in July following pH adjustment. It is not clear whether the increased gas production was a result of acclimation to the increased loading or the pH adjustment. pH levels rose to the 7.7 to 7.8 range later in August, however, and gas production remained high in proportion to the high COD removals occurring. It was concluded that within the pH range and at the ammonia concentration levels being studied that inhibition due to unionized ammonia was minimal or non-existent. Certainly there were no dramatic toxic effects evidenced by a cessation of gas production.

On July 26, the average loading rate was increased to 17.7 kg COD/m^3/d during the first 7 days of August. The resulting COD removal was 71 to 81% and BOD removal was 92 to 94%. On August 8 the loading to the filter was raised to 20.5 kg COD/m^3/d, 80% COD removal and 95% BOD removal was observed.

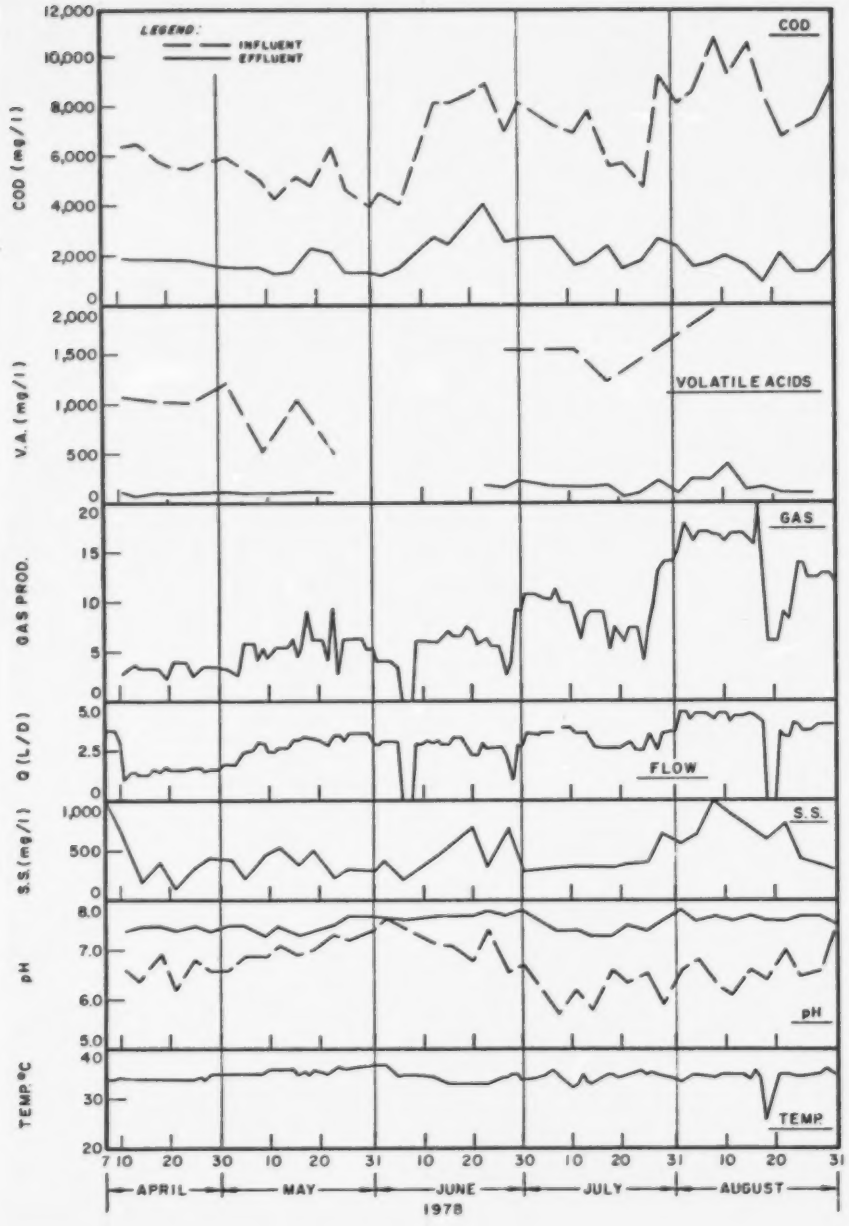


Figure 24. Anaerobic filter laboratory units chronological plots.

Gas production was averaging 17.0 1/d and rose as high as 20.5 1/d. The clean bed detention time in the column was 0.5 days based on the clean bed volume of 2.5 liters. Actual detention would be significantly less if the volume occupied by solids was taken into account.

Steady State Data

Selected study periods when the filter was operating at relatively steady state are shown in Table 26. During these periods, filter operation and feed concentrations were constant. The removal percentages of COD and BOD, shown in Figure 25, were relatively constant for most of the study, however, higher removals were observed at the higher loading rates imposed toward the end of the study. Gas production averaged 0.55 m^3/kg COD removed, (total-filtered) and 0.49 m^3/kg COD_R soluble basis, similar to that observed with the pilot plant. The COD removal versus COD loading rate and hydraulic detention time are shown in Figure 26. The removal rate appears to increase as the loading rate increases and the hydraulic detention time decreases. For example, from 7/28 to 8/4/78, the loading rate was 14.4 kg COD/m^3/d with a soluble COD removal of 66% and soluble BOD removal of 90%, and one month later under the same loading conditions, the soluble COD and BOD removal had increased to 72% and 95% respectively. This is attributed to additional accumulation of slow growing methane forming organisms in the filter as the study proceeded.

Solids Loading Basis

The laboratory filter was disassembled at the end of September to determine the amount of solids growth and the void volume of the filter. The total empty bed column was drained and 0.75 liters (30% void volume) with a suspended solids concentration of 2580 mg/1 was recovered. Several pieces of media were pulled from three depths and washed clean. Solids were measured and the results are tabulated in Table 27.

TABLE 27. LAB FILTER - SOLIDS

Depth From Bottom Meters	Attached Growth g solids per piece media	Attached Growth g per m^3 of empty column
1.2	111	20,800
0.6	163	30,600
0.2	190	35,631

The average solids concentration in the lab filter allowing for the media volume porosity 85%, was 26.4 kg Solids/m^3. Based on the solids measured in the filter, the calculated range of loading in terms of kg COD per kg solids per day was 0.19 to 0.55 kg COD/kg Solids/day. The equivalent volumetric loadings were 6.7 to 20 kg COD/m^3/d. Loading rates on the solids basis were somewhat higher than applied to pilot Column 1 and within the overall range applied to pilot Column 2.

TABLE 26. LABORATORY ANAEROBIC FILTER OPERATION SUMMARY

Date	Flow 1/d	Deten. Time Days	Loading[§] Rate kg COD/m^3/d	Gas Prod. 1/d	m^3 of gas* / kg COD_R	COD Removed T-F %	BOD Removed T-F %
5/5-5/9	2.7	0.8	6.7	5.31	.53	71	85
5/25-5/31	3.4	0.6	7.1	6.43	.61	70	92
6/2-6/5	3.0	0.7	6.3	4.10	.46	68	92
6/16-6/20	2.9	0.7	11.6	6.92	.40	70	87
7/7-7/11	3.6	0.6	12.3	10.28	.58	68	88
7/28-8/4	3.5	0.6	14.4	16.70	.75	74	93
8/4-8/15	4.3	0.5	20.1	19.60	.57	81	95
8/25-8/31	3.7	0.6	14.0	12.80	.55	79	96

* Based on influent COD or BOD total and effluent COD filtered

§ Based on solids measured in filter at end of study range of loading rates on solid basis is 0.22 to 0.65 kg COD/kg solids/day

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE

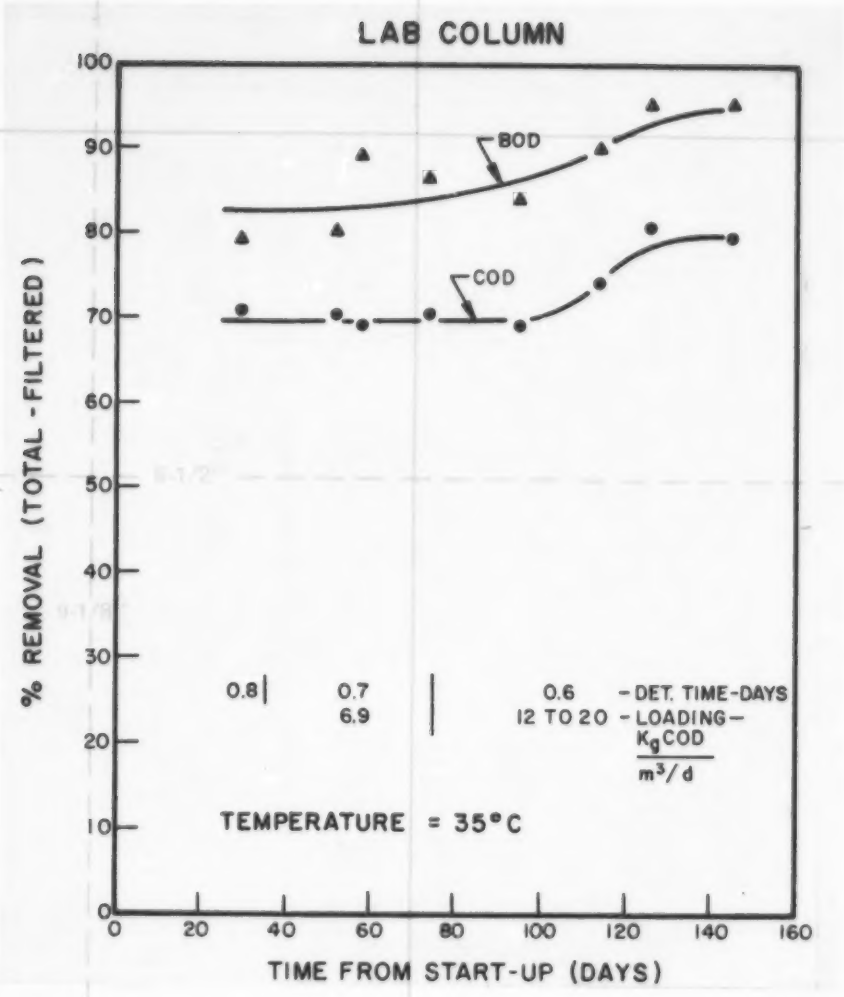


Figure 25. Laboratory anaerobic filter BOD and COD removal.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
C/B"

EPA-287 (Cin.)
(4-73)

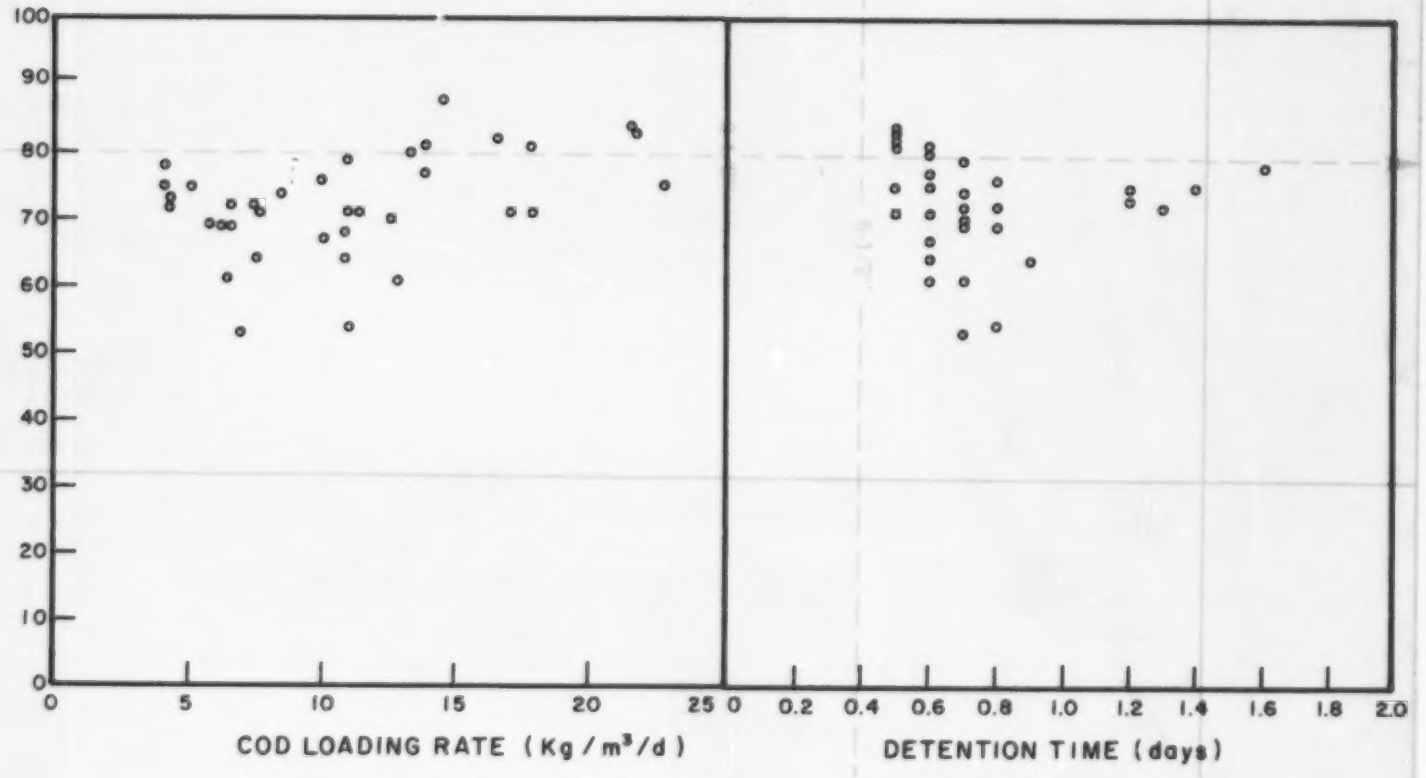


Figure 26. Laboratory anaerobic filter COD removal versus loading rate and detention time.

The concentration of attached solids measured in the lab unit averaged about three times greater than that found in the pilot plant filter at the conclusion of the study. This may be attributed to a number of factors including heavier initial seeding, longer period of operation at higher loading rates, and the greater surface area per unit of volume of the smaller media used in the lab filter. No difficulty with respect to this level of solids in the lab unit interfering with the hydraulic flow, or causing excessive pressure loss through the filter was experienced.

LABORATORY ANAEROBIC BATCH DIGESTORS - RESULTS

Start-up

The two batch digestors described in Section 5 were started up in September 1977. Unit A was seeded with 2.5 liters of sludge from the pilot anaerobic filter and Unit B was seeded with 2.5 liters of digesting sludge from the Bergen County Sewage treatment plant. The units were fed twice a week by removing a volume of digestor contents and replacing it with HTL feed. The overall detention time was 24 days and the units were operated at 35°C. Initial solids in the digestors were Unit A - 3.0%, and Unit B - 2.2%.

Chronological Data

Figure 27 presents a chronological plot of gas production and soluble COD in the effluents from the units. Influent COD values are also shown. It can be observed that gas production generally correlated to the strength of the HTL feed.

Initially, Unit A produced little gas, while Unit B began producing gas immediately. The low gas production, in the lab unit was consistent with what had been observed in the pilot filter columns and indicated a low level of active methane organisms in the sludge. One hundred milliliters of active sludge from Unit B was introduced as additional seed into Unit A on 9/23. Shortly thereafter and concurrent with the introduction of the higher strength HTL, gas production in Unit A increased. Effluent COD levels also increased as the initial seed sludge volume was displaced with the higher strength HTL and the gas producing microorganism population began to build up during the first month or so.

Although the units were allowed to settle prior to effluent withdrawal and feed, a considerable amount of solids were non settleable and were lost in the effluent. By November 7, the solids were down to 0.48% in Unit A and 0.51% in Unit B. Additional digesting sludge was added to Unit B to increase the solids concentration to 1.06% on November 11. An immediate increase in gas production was observed. Unit A gas production, however, also increased concurrent with the introduction of a higher strength feed. In December, Unit B produced slightly more gas and had a lower effluent COD than Unit A. Solids in the units in December were .21% and 0.48% for Unit A and Unit B. The higher solids level and the apparent greater activity of the solids during the study resulted in the lower effluent COD concentration in Unit B.

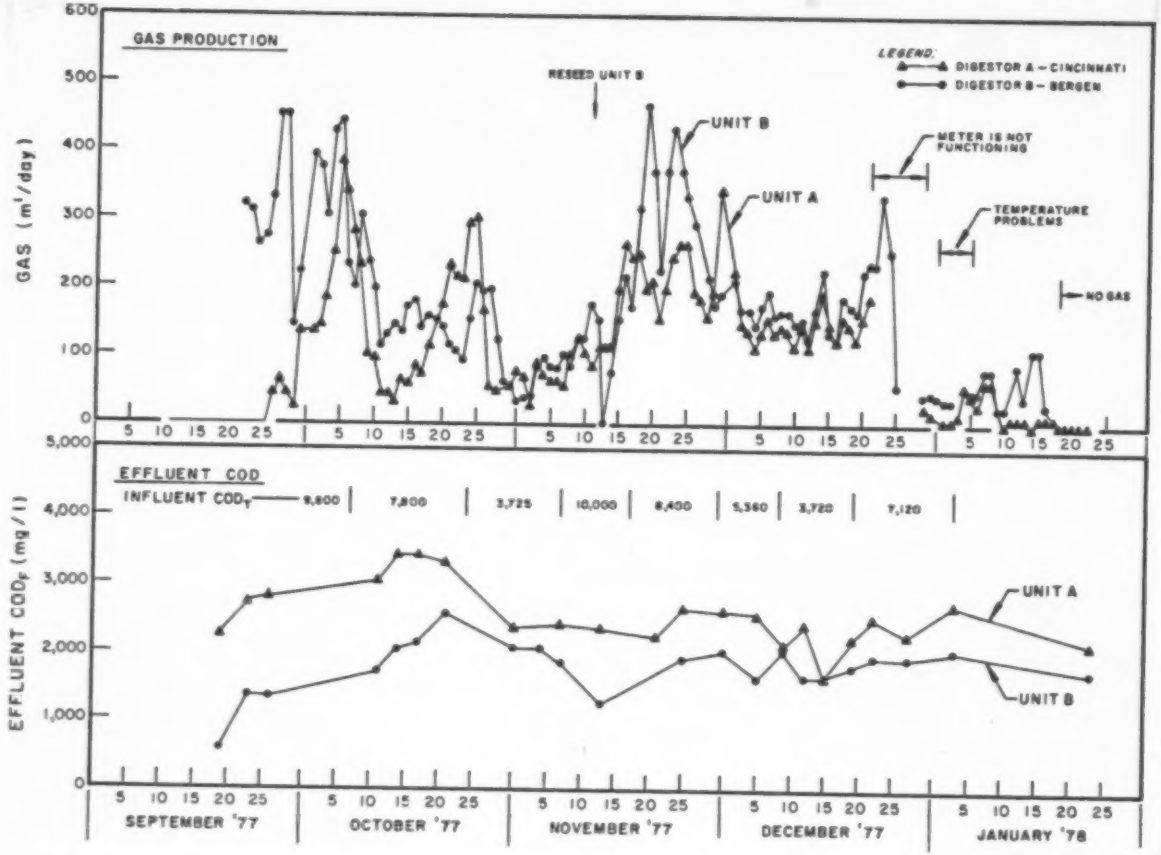


Figure 27. Laboratory batch digestors - chronological plot.

BOD - COD Relationship

Figure 28 compares soluble effluent BOD and COD. The curve through the data indicates that non biodegradable COD averaged about 1400 mg/1, slightly higher than was found during the Phase II study. Table 28 summarizes results for the digestors for November and December. With 24 days detention, the hydraulic loadings averaged 10 to 50 times less than on the pilot plants. Removals were calculated on the basis of average COD and also on average biodegradable COD determined by subtracting 1400 mg/1 from influent and effluent COD values. As can be observed, Unit B, the Bergen County Sludge, at the higher solids concentration produced a better effluent and achieved greater removals than Unit A. Unit A, operating at about double the loading per unit solids, however, removed a significant percentage of the applied COD. The amount of gas produced by both units per unit of COD removed was essentially the same.

The results from operation of these units demonstrated that the COD in heat treatment liquor is reduced by anaerobic digestion and that the HTL in the concentrations fed, does not appear to cause any inhibitory effect. The results illustrate the effect of the solids concentration and loading per unit solids, on COD removal efficiency, as a loading parameter, compared to the use of a loading per unit volume parameter. The loading in Unit A is approximately in the range of loading applied to pilot filter Column 1 and the removal of 60% COD is comparable to that observed in the filter. The lower loading in unit B resulted in an increase in removal to about 70%. This is comparable to the soluble COD removal observed in the laboratory pilot filter, although at significantly higher (10 times or more) loading.

The nature of the solids and concentrations of viable microorganisms is important. These results indicate that maximum removals of COD from the HTL studied in this project by anaerobic treatment would be in the order of about 70%. Based on the extrapolated average biodegradable fraction, biodegradable COD removal would be in the order of about 90%.

REMOVAL KINETICS AND SELECTION OF DESIGN PARAMETERS

Comparison of Pilot Plant and Laboratory Filter

The results during the latter part of the study when the filters were achieving their highest removals, were used to scale-up to a full scale unit. The laboratory bench-scale study results along with the significant differences in results between the lab unit and pilot units were considered. Significantly higher removals were achieved in the lab column compared to the removals in the full scale pilot plant. See Tables 19, 20 and 26.

At a detention of about 0.7 day and loading of about 9.4 kg COD/m^3/d, pilot plant Column 2 achieved 55% COD removal and 78% BOD removal compared to removals of 76% COD and 94% BOD at 0.6 days detention and a loading of 14 kg COD/m^3/day in the lab bench scale unit. This result indicates the importance of the retention of solids in the column on removals. Although the volumetric loading was lower and detention time longer, the pilot columns did not

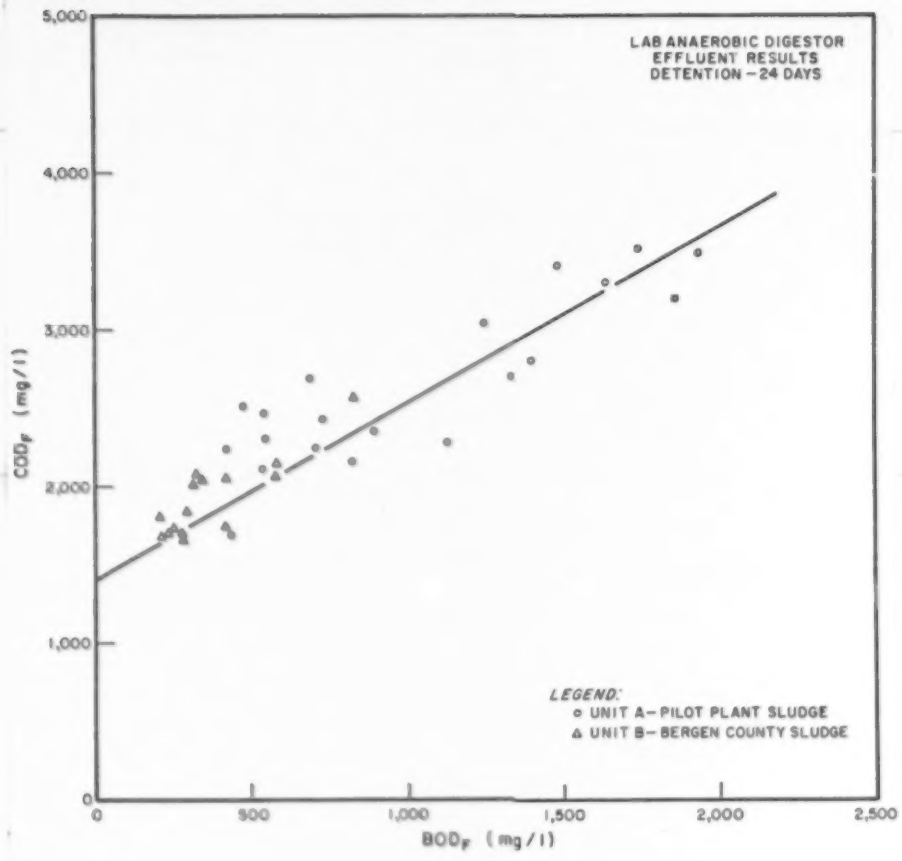


Figure 28. Soluble effluent BOD – COD relationship-lab digestor study.

TABLE 28. LABORATORY MIXED ANAEROBIC DIGESTORS
SUMMARY OF OPERATION AND RESULTS
NOVEMBER - DECEMBER 1977

	Inf. COD mg/l	Avg. Eff. COD mg/l	Avg. MLSS mg/l	LOADINGS kg COD/m^3/d	LOADINGS kg COD/kg/d	COD Removal %	Gas m^3/kg COD_R
Unit A	6390	2550	2950	0.23	0.080	60	0.35
Unit B	6390	1900	6170	0.23	0.038	70	0.37

Average Feed Rate 0.11 1/d
Detention time 24 d

COD Removals based on biodegradeable COD (COD_T-1400): Unit A - 77%, Unit B - 90%

perform as well as the lab unit. The higher volumetric loading and lower detention time, in the lab unit was at an approximate loading, on a solids basis, or half the loading applied to the pilot column, as a result of greater solids retention with the smaller media.

Physical differences of the units are obvious but the most critical difference was the size of media being used. The pilot units media had an effective surface area of 102 m^2/m^3. The surface area of the bench scale media was 341 m^2/m^3, which provided 3.3 times more surface area per unit volume. The smaller media provided a greater opportunity for retention of attached growth. The laboratory unit had approximately 3.5 times greater concentration of attached growth than Column 2.

Based on the pilot plant results, an average solids concentration was in the order of 10 kg solids/m^3. The lab unit indicated excellent removals of up to 80% COD, 95% BOD, at COD to solids loadings of up to 0.55 kg/kg, while the results of operation of the pilot filter columns indicated lower efficiencies of 65% to 70% COD and 85% BOD at 0.2 kg/kg/d filter Column 1 and 55% to 60% COD and 70% BOD at 1.0 kg/kg/d for filter Column 2.

Kinetics

Removal rate of COD in anaerobic treatment is essentially equivalent to the rate of conversion of volatile acids to methane and CO_2. Based on solids measured in the pilot and lab filters (Tables 25 and 26) and removals measured during the last several days prior to dismantling the columns to measure solids, a first order kinetic relationship was developed. Dye studies in the pilot columns had shown a high degree of mixing. Volatile acids measurements at each tap, Table 25, indicated complete mixing in Column 2, and two zones of activity in Column 1. For these analyses, Column 2 was considered completely mixed while Column 1 was assumed completely mixed in the lower 0.6 meters. The lab column was 1.2 meters tall. Previous studies indicated that this size column exhibits a plug flow regime. Since no data of removal with depth was collected, a completely mixed reactor was also assumed, for comparison.

Figure 29 presents the results of the analyses. An average non-biodegradable COD value of 1200 mg/l was used as the origin for the curves. Column 1 removal rate was quite low, however, the lab column and Column 2 data agreed. The reaction rate constant of 0.0004 (kg COD removed/da)/(kg column solids)/(mg degradable COD/l) was similar to that found by Mueller and Mancini[25] in their evaluation of plug flow anaerobic filter data. The low rate in Column 1 is indicative of the high solids concentration in the lower foot being essentially inert solids which were not "washed out" of the filter as apparently was the case with Column 2 at the higher flow rate.

The difference in rates between the two columns, and with higher rates reported elsewhere[3] is related to the mass of methanogenic organisms retained in the filter after the period of operation. Much higher rates of removal with similar effluent quality would appear possible, however, only after longer periods of operation at increasing loading rates, and the development of greater mass of attached biological solids.

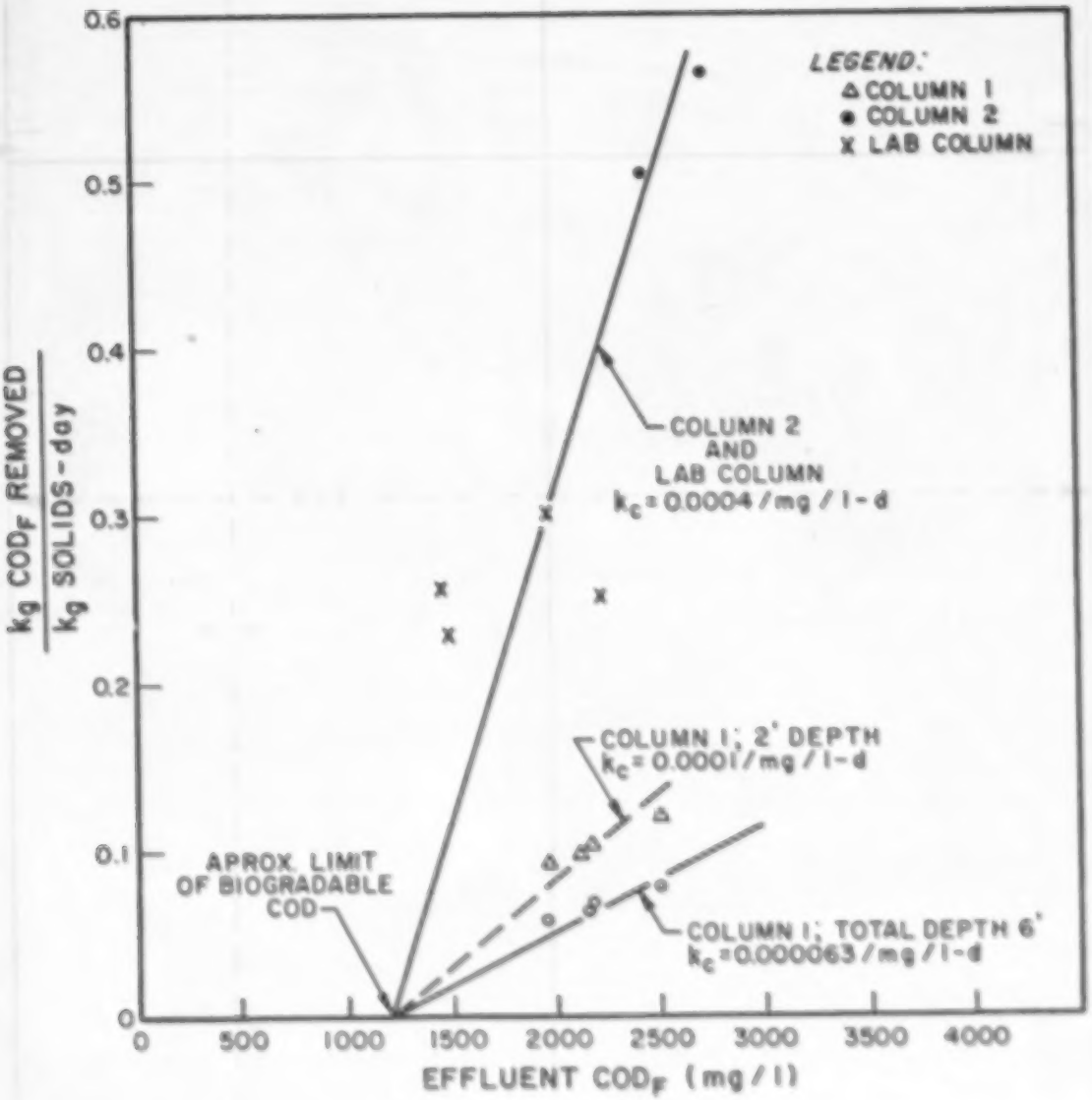


Figure 29. COD removal rate.

Sizing and Estimated Removal Efficiency

The development and retention of methane forming organisms in the filter is the major factor in the differences observed between the lab unit and the full scale column. The longer period of operation and greater solids concentrations retained by the small media in the lab column resulted in the greater removals achieved. The practical considerations of lower media cost and lesser possibility of eventual solids plugging, favor the use of the larger pilot plant media for a full scale plant, accepting possibly somewhat lower removals and lower volumetric loadings than with the smaller lab type media. The gradual increase in the removal efficiency of the pilot columns and the higher solids concentrations developed in the lower sections would indicate that reasonable loadings with the larger media would eventually result in removal efficiency levels observed in the laboratory filters.

The pilot unit achieved reasonable removals at less than 1 day detention at the end of the study. A more conservative approach to selection of a design detention, based on the pilot plant and lab studies considering both detention, and solids retention, is taken at this time, to size the anaerobic filter for purposes of cost comparison. A detention time of 1.5 days was selected. Based on the waste COD concentration of 10,750 mg/1, this results in a loading of 7.2 kg COD/m^3/day. Assuming a solids concentration of 10 kg/m^3, the loading on a solids basis would be 0.72 kg/kg/day.

Minimum removals of at least 55 to 65% COD and 75 to 85% BOD would be expected based on the Column 2 results, as shown in Figures 14 and 15. The kinetic reaction rate determined for the lab column and Column 2, Figure 29, would predict, at a removal rate of 0.47 kg COD/kg solids/day, an effluent of about 2500 mg/1 or a percent COD removal of about 76% at the 10,750 mg/1 influent.

The apparent limit of COD removal of about 70% exhibited for a long portion of the study by the lab column (Figure 20) and achieved by the Column 1 at the end of the study is selected as the probable removal in the filter. The equivalent removal of BOD would be 85%.

AEROBIC PILOT STUDY

The aerobic pilot units were run from 8/13/78 to 9/15/78. Two units were operated under present and projected loads for the Muddy Creek STP. These units were evaluated to determine the effect of HTL on an activated sludge treatment system.

Treatment plant data collected at Muddy Creek in November and December 1974, when the heat treatment system was operating, and in January 1976, when the system was not operating, are compared in Table 29. These data indicate that the HTL liquor return causes significant impact on the treatment plant and on its ability to meet the design effluent of 10 mg/1 BOD and 12 mg/1 suspended solids. There may have been other circumstances contributing to the higher effluents when the heat treatment system was running, however, experience at other plants have been similar.

TABLE 29. EFFECT OF HTL ON ACTIVATED SLUDGE AT MUDDY CREEK STP

Date	Avg. Plant Flow m^3/d	HT Operation Days	Avg. Flow of HTL m^3/d	BOD Avg. mg/l	BOD Range mg/l	Avg. SS mg/l
Influent						
11/74	32,200	26	212	84	22-145	142
12/74	29,500	21	167	75	16-121	100
1/76	27,300	0	0	67	26-105	130
Effluent						
11/74	32,200	26	212	17*	3-90	28*
12/74	29,500	21	167	20	2-154	35
1/76	27,300	0	0	4	2-6	10

*November 25-30 excluded, due to obvious upset conditions when effluent BOD = 265 mg/l and suspended solids = 996 mg/l

The pilot units were seeded with activated sludge from the Muddy Creek STP aeration basin on 8/13/78. An initial MLSS concentration of 1300 mg/1 was set. The primary effluent from the plant used to feed the units had a BOD of 70 mg/1 or less. Floating sludge in the secondary clarifier was an occasional problem attributed to denitrification. The sludge recycle rate was increased to 100% of the influent flow in order to lower the sludge detention time in the clarifier. During the ten days of operation with primary effluent only being fed, the effluent COD_T averaged 12 and 16 mg/1 in units A-1 and A-2, respectively.

HTL was fed to unit A-1 and the effluent from anaerobic filter Column 1 was fed to unit A-2. The treated raw HTL feed to the units was 0.8% of the total flow. Table 30 presents the operation summary of each unit during periods of steady flow rates. The HTL and primary effluent characteristics were variable causing the loading to vary. During the first loading period from 8/24 to 9/8. The MLSS was allowed to increase without sludge wasting. Effluent BOD increased initially to 30 mg/1 but returned to the 14-18 mg/1 range, about the same level prior to HTL addition. The effluent COD increase noted was due to the non-biodegradable fraction of COD in the HTL (1200 mg/1), which from 8/24 to 9/8 was 7 mg/1. The higher loading rate to unit A-2 was due to the lower MLSS concentration of 950 mg/1, compared to unit A-1 MLSS of 1570 mg/1. The COD_T effluent values were in the range of 40 mg/1. The Muddy Creek treatment plant effluent COD_F was reported at 71 mg/1 and the BOD_T was 12 mg/1 during this period.

The second loading period was from 9/8 to 9/15. The MLSS's were adjusted to approximately 1000 mg/1 in each unit. HTL flow was doubled and the MLSS was allowed to vary without sludge wastage. During this period, the units experienced floating sludge in the clarifier which caused solids losses to occur and reduced the MLSS concentration. The F/M loading in unit A-1 increased from 0.12 to 0.20 kg BOD/kg MLSS-d. The effluent BOD and suspended solids were slightly lower than the previous loading period. The F/M loading to unit A-2 was 0.17 kg BOD/kg MLSS/d and the effluent BOD ranged from 25 to 18 mg/1. In both units the effluent COD increased about 13 mg/1 due to the increase of non-biodegradable COD contributed by the HTL. The Muddy Creek treatment plant BOD_T was 11 mg/1 with a COD_T value of 14 mg/1.

The effluent BOD for the units averaged 18 mg/1 while the Muddy Creek STP averaged 11 mg/1. This difference may have been due to the HTL feed, however, the variable operating conditions and the short period during which the pilot study was conducted preclude a definitive conclusion.

The oxygen uptake data were correlated with COD removal and the results are shown in Figure 30. The data include all three operating conditions since there did not appear to be a significant difference among them. The following relationship was determined for oxygen requirements at 23°C.

$$\text{Oxygen required (kg/d)} = 0.82\ COD_R\text{(kg/d)} + 0.05\ \text{MLSS (kg)}$$

This equation includes the nitrification that was taking place in the pilot units. The nitrogen load to each unit and the approximate amount of nitrification taking place was calculated by use of data from the Muddy Creek STP.

TABLE 30. PERFORMANCE SUMMARY
UNIT 1 AND UNIT 2 - 8/29 - 9/8/78

	F/M kg COD kg MLSS	Dissolved Oxygen mg/l	BOD_T Effluent mg/l	Suspended Solids mg/l	Oxygen Uptake mg/l/hr
Unit 1 - Raw HTL					
Range	.16-.21	2.9-6.0	9-20	12-19	13-18
Average	.19	3.8	14	16	16.2
Unit 2 - Anaerobic Filter Effluent					
Range	.19-.27	2.8-5.8	13-20	6-24	10.6-20
Average	.23	3.7	17	14	13.3

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE

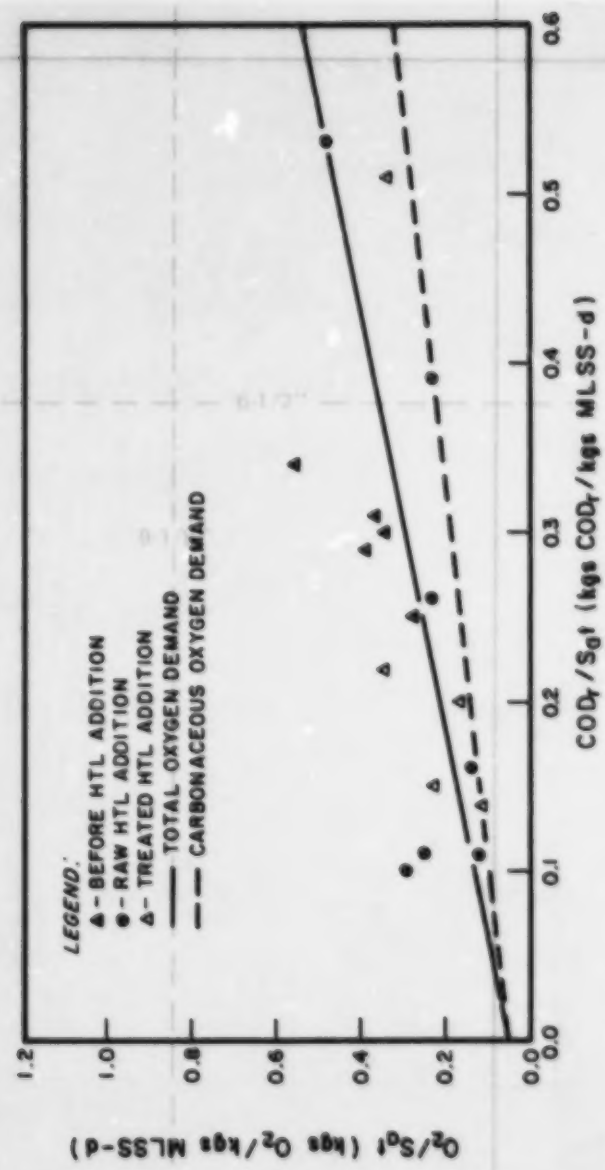


Figure 30. Aerobic pilot unit oxygen utilization.

BEGIN LAST LINE OF TEXT
3/8"
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

EPA-287 (Cin.)
(4-76)

The oxygen equation for carbonaceous removal was then recalculated as:

Oxygen required (kg/d) = .43 COD_R(kg/d) + 0.05 MLSS (kg)

Biological solids production was determined for both units by calculating a solids balance around each unit. The net sludge production from 8/29 to 9/8 was 0.28 and 0.25 kg SS/kg COD_R(T-F) in unit A-1 and unit A-2 respectively. The sludge production was also calculated by relating the carbonaceous oxygen equation to solids production as follows:

Sludge Produced (kg) = 0.40 COD_R(kg/d) - 0.04 MLSS (kg)

The aerobic pilot units did show that the HTL had an initial effect on the effluent BOD but after several days of continual HTL addition, the effluent BOD was reduced near to pre-HTL addition levels. The HTL appeared to have little adverse effect on the quality of the effluent, but a longer pilot study would be required to come to a more conclusive observation. The low BOD of the primary effluent and its variability resulted in changing conditions making an accurate analysis difficult. The primary effluent with recycled treated HTL and raw HTL had about the same biodegrable characteristics and oxygen utilization ratios. The greater quantity of BOD added by the raw HTL, reveals significantly more oxygen and produces more solids compared to anaerobically treated HTL.

Effluent limitations on the amount and form of nitrogen, NH_3 or NO_3, may require nitrification and denitrification in treatment plants where HTL is recycled since the nitrogen loads in return HTL are quite significant.

SECTION 7

ANAEROBIC FILTER DESIGN AND COST ESTIMATES

INTRODUCTION

A purpose of the pilot plant study was to develop a design for an Anaerobic Filter for heat treatment liquor at the Muddy Creek plant and to compare its economics with separate aerobic treatment or treatment of the liquor in the main plant activated sludge facilities. In this section, the design parameters developed from the anaerobic filter studies described in the previous section are utilized to size an anaerobic filter for the heat treatment liquor. The heat treatment liquor volume and characteristics are based on the design values for the heat treatment system at the Muddy Creek plant at full design flow of 56,780 m^3/d (15 MGD), and design influent sewage characteristics. Table 31 presents the design data for the raw heat treatment liquor, the design parameters selected for sizing the anaerobic filter, and aerobic treatment facilities. Design values on the heat treatment liquor volume, solids and aeration systems were obtained from the Muddy Creek plant operating manual and are indicated by an astrick, while the other values were based on data and results of the studies in Section 6.

ANAEROBIC FILTER DESIGN

Filter Volume

The sizing of the volume of media required for the HTL anaerobic filter is based on the detention time parameters. As noted in Section 6, the pilot filter performance was reasonable and appeared to be improving at the end of the study at a detention of less than one day, however, for purposes of this design, a more conservative detention time of 1.5 days has been selected.

Filter Volume: $1.5\ d \times 340\ m^3/d = 510\ m^3$

The corresponding loadings are:

$$\frac{3640\ kg/d}{510\ m^3} = 7.1\ kg/m^3/d$$

and

$$\frac{3640\ kg/d}{10\ kg/m^3 \times 510\ m^3} = 0.72\ kg/kg\ solids/d$$

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD. BEGIN SECTIONS HERE

TABLE 31. DESIGN BASIS

Raw Heat Treatment Liquor

Combined decant tank and filtrate from vacuum filters

Volume - 340 m^3/day (*)

Temperature - 25 to 55°C

COD - 10,750 mg/l (3640 kg/d)

BOD - 4900 mg/l (1700 kg/d)

SS - 6400 mg/l (2170 kg/d) (*)

Anaerobic Filter Treatment

Detention Time days	1.5
COD Loading kg/m^3/d	6.5
COD Loading kg/kg/d	0.65
Soluble COD Removal %	55 - 70
Soluble BOD Removal %	75 - 85
Estimated Sludge Production	0.1 COD_R
Media (9 cm) Porosity %	0.95
Gas Production m^3/kg COD_R	0.5
Methane Content %	65 - 70
Heating Value kg-cal/m^3	5300

Aerobic - Activated Sludge Treatment

BOD Loading kg/m^3/d 0.59 (*)

BOD Loading kg/kg/d 0.24

Mixed Liquor Suspended Solids mg/l 2500 (*)

Oxygen Requirements = 0.43 COD_R + 0.05 MLSS x V

Sludge Produced = 0.40 COD_R - 0.04 MLSS x V

* From Muddy Creek STP Operation Manual

BEGIN LAST LINE OF TEXT HERE
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

EPA-287 (Cin.)
(4-76)

Filter Depth

The pilot studies were conducted with 1.8 m and 3 m of media depth. In the design flow range, Column 2 exhibited complete mixing characteristics at 1.8 m depth, as well as uniform solids growth on the media. Use of greater depths in a full scale design would be somewhat more economical based on filter configuration and influent distribution. A greater media depth at full scale would also result in a filter with less heat loss. Feeding influent at two or three points in the depth of the media may provide distribution and mixing similar to that in the pilot plant, and permit higher loadings. To evaluate the need and possible advantage of deeper media and step feeding, further testing would be required.

While a detailed design study, which is beyond the scope of this study, would be required to develop the most economical and practical filter and influent distribution techniques (upflow, step feed, completely mixed with upflow, etc.), a preliminary sizing for purposes of developing a cost estimate was developed. A filter of 12 m diameter with 5 m of media, and 1.5 m below the media for media support, distribution of influent, and settleable sludge draw off zone, and 2.5 m above the media for effluent withdrawal and gas collection is used for cost estimation. The greater depth of media is selected to achieve a more economical design with lower heat losses.

It is recognized, however, that the pilot plants evaluated a media depth of 1.8 m. Since the more conservative detention time of 1.5 days, versus 1 day or less at which performance was fairly good and improving at the end of the study, was selected, the cost estimate is based on the less costly 5 m deep bed rather than a design using 2 m depth. As previously indicated, further testing to verify performance both at lower detention time and higher loading, and greater media depths would be recommended. The construction of the anaerobic filter would generally be similar to a conventional anaerobic digestor, with the exception of the media support, the influent distribution system, and an effluent withdrawal collection system above the media to promote optimum distribution and flow characteristics through the filter bed. Figure 31 presents a schematic process flow diagram for the suggested anaerobic filter design.

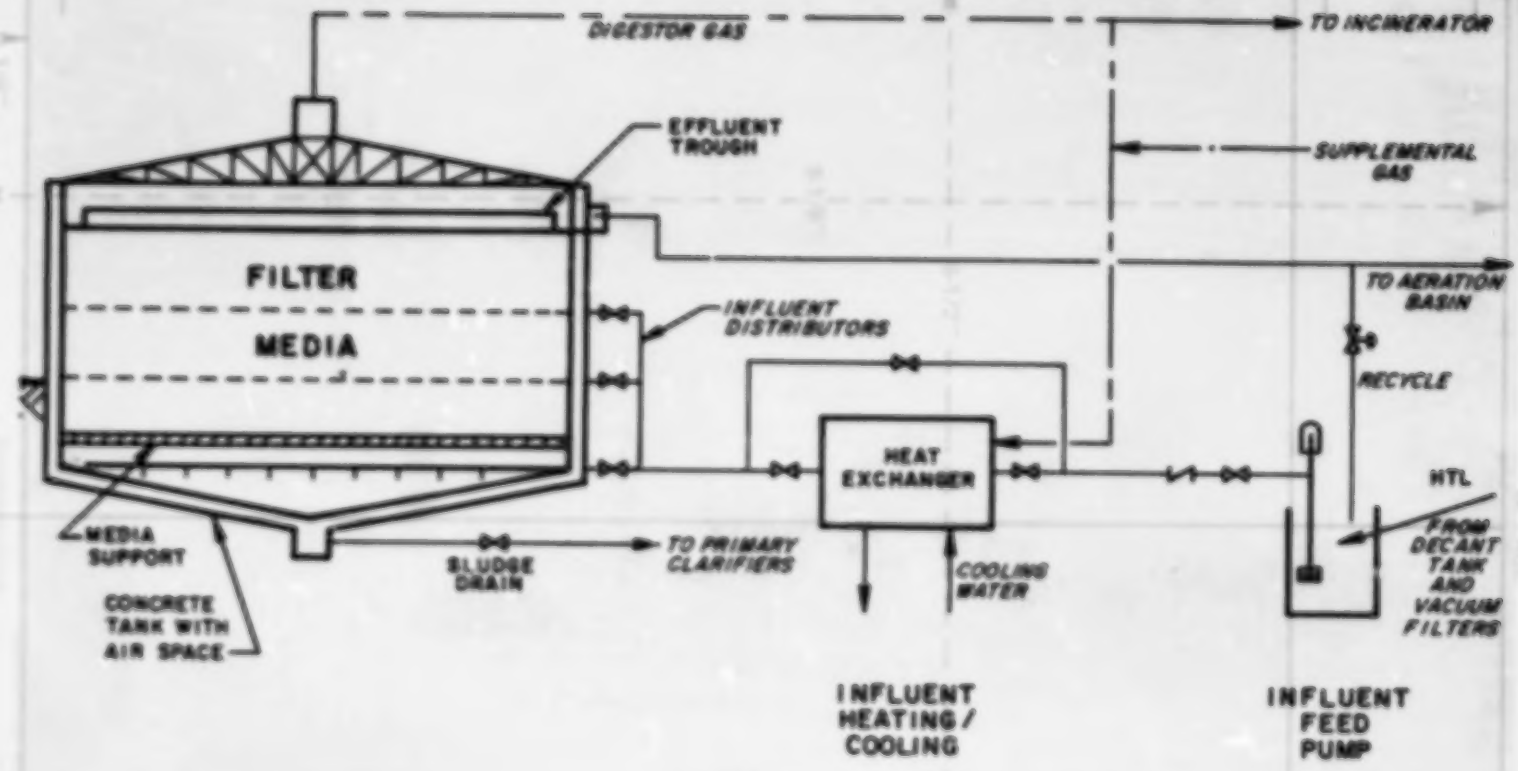


Figure 31. Schematic anaerobic filter system.

Table 32 presents alternate designs of an anaerobic filter for heat treatment liquor.

TABLE 32. ALTERNATIVE DESIGN OPTIONS

	Anaerobic Filter	
	Deep Tank	Shallow Tank
Loading		
COD - $kg/m^3/d$	7.1	7.1
Detention Time - days	1.5	1.5
Filter Volume - m^3	510	510
Depth - Media m	5	2
Infl. Distr. & Sludge draw off - m	1.5	1.5
Gas Collection - m	2.5	2.5
Diameter m	12	18

The shallow tank design conforms to the pilot plant system, i.e., effective media depth. The deep tank which has been selected herein for cost comparison is, we believe, a reasonable extension of the pilot plant system. The increased depth from the approximately 2 meter pilot depth to the 5 meters is felt reasonable since tracer studies indicated pilot units were essentially completely mixed and the biological solids were essentially attached to the media.

Temperature Considerations --

Heat treatment liquor discharged from the thermal reactor is passed through a heat exchanger to heat incoming sludge prior to discharge to the decant tank. The heat treatment liquor may also be cooled further in a heat exchanger, depending upon the design and operation of the thermal heat treatment and sludge dewatering systems. Controls to adjust HTL temperature to meet the requirements of the anaerobic filter may be possible and would be considered in design. At Muddy Creek, the heat treatment liquor will vary in temperature but is usually quite warm and temperatures in the range of 35°C above ambient are indicated in the design manual. Some cooling will occur in the decant tank and in the vacuum filter operation prior to the liquor being fed to the anaerobic filter. Estimated maximum and minimum temperatures of heat treatment liquor available for feed to the filter are 60°C and 25°C respectfully for this application. In this case, therefore, both heating during the winter and cooling during the summer are assumed necessary to maintain close control of temperature in the anaerobic filter.

Heat Loss --

The optimum treatment temperature of 35°C has been selected for design of the filter, thus heat losses must be considered in an overall energy balance for the process. Loss of heat from the filter was computed by the following equation:

$$Q = UA(T_w - T_l)$$

Q = heat loss
U = heat transfer coefficient
A = surface area
T_w = filter temperature 35°C
T_l = Ambient temperature

Common coefficients for digestors were used and the maximum and average heat losses were calculated:

Maximum - 3.8×10^6 kg-cal/d @ -18°C Ambient
Annual Average - 1.6×10^5 kg-cal/d @ 13°C Ambient
Annual Minimum - 3.6×10^5 kg-cal/d @ 30°C Ambient

To maintain 35°C in the filter and to supply the additional heat to make up for losses would require influent temperatures to the filter (at 340 m^3/d flow) of approximately:

Minimum summer - 36°C
Average annual - 40°C
Maximum winter - 46°C

Based on this table and the range of MTL temperatures, heating will be required in the winter and cooling in the summer to maintain temperature in the filter.

Heating-Cooling Requirements --

A heat exchanger to provide the maxium heating requirements in wigter to heat the MTL from 25°C to about 46°C would be sized for about 4.8×10^5 kg-cal/hr. On an average annual basis, the total heating requirement would be approximately 4×10^8 kg-cal which includes heat supplied to effluent recycle on weekends to maintain filter temperature.

A heat exchanger to provide maximum cooling requirements in summer from 55°C to 36°C would be sized for about 4.5×10^5 kg-cal/hr. Cooling water flows required would range from 200 to 300 l/min.

Energy Produced --

The gas produced by the anaerobic filter has a methane content of 65 to 70% and is therefore a valuable product which can be used for heating. The gas will be provided continuously during MTL feed to the anaerobic filter and can be used for heating the influent when required in cold weather. Excess gas, when not required for the filter could be used for other plant heating requirements such as the odor control burner on the decant tank, the sludge heat treatment reactor or the sludge incinerator.

Heating value of the gas produced per day is:

3640 kg COD x 60% removed x 0.5 m^3/kg COD_R x 5340 kg-cal/m^3 =
5.8×10^6 kg-cal/day

Under maximum winter conditions, about 7.5×10^6 kg-cal/d would be required to heat the influent HTL from about 25°C to 46°C, thus, supplementary fuel would be required for those maximum days, as well as during periods of effluent recycle to maintain temperatures. On an annual basis, the additional energy available for other uses generated by the anaerobic filter would be approximately:

$(5.8 \times 10^6 \times 5 \times 52) - 4.0 \times 10^8 = 1.11 \times 10^9$ kg-cal/year

AEROBIC SYSTEMS DESIGN

The Muddy Creek plant has designed into the aeration basins, aeration system and sludge handling system, additional capacity to handle the return heat treatment liquor. This additional capacity has been calculated based on the design parameters used to size the Muddy Creek plant.

$$\text{Aeration Volume} = \frac{1700 \times .75}{.59 \text{ Kg/m}^3\text{/d}} = 2160 \text{ m}^3$$

Oxygen Required = $0.43(3640 \times .55) + .05(2.500 \times 2160) = 1130$ kg/d

Note: % removal of BOD and COD used is the same as for a filter, so that the volume, and oxygen required are the additional requirements representing the difference between HTL and anaerobicly treated HTL.

Sludge Produced = $0.4(3640 \times .55) - .04(2.500 \times 2160) = 585$ kg/d

% Additional Capacity:

$$\text{Aeration Volume } \frac{1700 \text{ kg/d BOD} \times .75}{7370 \text{ kg/d BOD*}} = 17.3\%$$

$$\text{Sludge Handling } \frac{585 \text{ kg}}{20{,}500 \text{ kg*}} = 2.9\%$$

*From design manual less allowance for untreated HTL return

$$\text{Clarifier Surface Area} = \frac{340 \text{ m}^3}{33 \text{ m}^3\text{/d/m}^2} = 10.3 \text{ m}^2$$

In the treatment plant, clarifier area would not be required for both treated and untreated HTL, however, in a separate pretreatment system a clarifier would be required for an aerobic system.

COST COMPARISON

Costs were developed for an anaerobic filter and for aerobic treatment of heat treatment liquor. With respect to aerobic treatment incorporated into the plant design, the cost determined is the incremental cost difference between treating raw HTL and anaerobic filter treated HTL. Separate aerobic

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE

treatment of the HTL is considered as a completely separate treatment facility, utilizing the same design loadings applied to the full scale plant, however, the load applied is factored by the same percent removals achieved in the anaerobic filter, to obtain a reasonably comparative cost basis.

Cost data used was compiled from published EPA cost data as well as data from various sources including manufacturers data and in-house developed cost data. At the present state of design, that is selection of unit sizes and general equipment requirements, costs would be considered preliminary and in the order of ± 30%. Cost data was escalated to 1979 basis. Tables 33, 34, and 35 present the capital and operating cost estimates.

This cost analysis indicates that the anaerobic filter capital cost is less than the cost to incorporate aerobic treatment capacity for raw heat treatment liquor into a moderately sized (56,800 m^3/d) sewage treatment plant. There is, however, a substantial difference in operating costs particularly when credit is taken for the value of the methane gas produced by the anaerobic filter. A thorough and detailed cost analyses considering interest rates and financial strategy would be required to determine the benefit of installing an anaerobic filter in a sewage plant which already has the aerobic capacity for the heat treatment liquor included and is not overloaded. In the case of Muddy Creek, the plant is presently operating at only half design flow and its design included capacity to handle the heat treatment liquor. Based on the operating cost difference including credit for methane, the pay off for the capital cost to install an anaerobic filter would be about 9 years at 8% interest, assuming operation at design values. Since the plant presently is quite underloaded, it would not appear economically feasible at this time to install an anaerobic filter for HTL at the Muddy Creek Plant.

The significant difference between the operating cost of the anaerobic filter and the incremental cost for treatment in the plant would indicate that the anaerobic filter should be considered as a viable alternative in design of new or upgraded sewage facilities. The large differences in capital and operating costs for separate aerobic treatment would indicate that the anaerobic filter would be quite cost effective in cases where treatment facilities are at design loads and a sludge heat treatment system is to be added to the existing facilities.

BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"

EPA-287 (Cin.)
(1-76)

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE
6-1/2"
9-1/8"
BEGIN LAST LINE OF TEXT
3/8"
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
PAGE NUMBER
EPA-287 (Cin.) (4-76)

TABLE 33. ANAEROBIC FILTER COST ESTIMATE

Capital Costs	
Anaerobic Filter - Basis typical anaerobic digestor with roof, gas handling facilities, and influent heating/cooling exchangers, and instrumentation and controls. Total volume is approximately 1000 m^3	$279,300
Filter media - 9 cm pall rings - $106/$m^3$ - 560 m^3	59,400
Influent pumping station - 2 pumps @ 0-400 m^3/d, wet well, flow controls	27,000
Influent distribution, media support, gas line piping, excess gas burner - allow	25,000
Subtotal	390,700
Contingencies @ 20%	78,100
Total	468,800
Say -	$470,000
Operation and Maintenance	
Pumping - power costs - 15 kw @ 0.035 ¢/Kw Hr.	4,600
Maintenance Costs @ 3.5% of Capital Costs	16,450
Labor @ 1 hr/day - $15/hr	5,500
Cooling water 34,800 m^3/yr @ $0.05/$m^3$	1,800
	$28,350
Value of Excess Methane Gas	
1.13×10^9 kg-cal/year @ $\$40.00/10^6$ kg-cal	$45,200
Net Operation Cost (Savings)	-$16,850

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE

TABLE 34. INCREMENTAL COST ESTIMATE FOR AEROBIC TREATMENT

Capital Costs		
Aeration Basin 1700 m^3 Additional volume @ $78/$m^3$		132,600
Aeration Equipment 1840 l/s @ $93/l/s		171,100
Sludge Handling includes heat treatment, dewatering and associated facilities 595 kg/d @ $230/kg/d		139,900
	Sub Total	$443,600
	Contingencies - 20%	88,700
	Total	$532,300
	Say -	$535,000
Operation and Maintenance Costs		
Aeration Power - 78 Kw @ $0.035/Kw hr		$17,000
Maintenance @ 3.5% Capital Cost		18,600
Labor @ 1 hr/day @ $15/hr		5,500
Sludge Handling 155 MT/yr @ $93/MT		14,400
		$55,500

9-1/8"
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

EPA-287 (Cin.)
(4-76)

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE

TABLE 35. SEPARATE AEROBIC TREATMENT COST ESTIMATE

Capital Costs		
Aeration Basin 1700 m^3		$235,200
Clarifier - 5.5 m diameter		25,000
Aeration System - 1800 l/s		445,700
Sludge Handling 595 kg/d @ $230/kg/d		139,900
	Subtotal	$845,800
	Contingencies @ 20%	69,200
	Total	1,015,000
	Say -	1,015,000
Operation and Maintenance Costs		
Aeration Power 78 Kw @ $0.035/Kw-hr		$17,000
Maintenance @ 3.5% Capital Cost		33,600
Labor - 2 hr/day @ $15/hr		11,000
Sludge Handling - 155 MT/y @ $93/Mt		14,400
		$76,000

9-1/8"
BEGIN LAST LINE OF TEXT
3/8"
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

EPA-287 (Cin.)
(4-76)

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE

REFERENCES

1. Young, J.C. and McCarty, P.L., "The Anaerobic Filter for Waste Treatment," JWPCF, 41, R 160-R 173, 1969.

2. ibid, Technical Report, No. 87, Department of Civil Engineering, Stanford University, March 1968.

3. Lawrence, A.W. and McCarty, P.L., "Kinetics of Methane Fermentation in Anaerobic Treatment," JWPCF, 41, R 1-R 17, 1969.

4. Pohland, F.G. and Massey, M.L., "An Application of Process Kinetics for Phase Separation of the Anaerobic Stabilization Process," presented at the International Research Conference, Georgia Institute of Technology, October 1972.

5. Plummer, A.H., Malina, J.F. and Eckenfelder, W.W., "Stabilization of a Low Solids Carbohydrate Waste by an Anaerobic Filter," 23rd PIWC, 467-473, 1968.

6. Plummer, A.H., "Stabilization of a Food Processing Waste by the Anaerobic Submerged Filter," M.S. Thesis, University of Texas, 1968.

7. Clark, R.H. and Speece, R.E., "The pH Tolerance of Anaerobic Digestion," 5th International Water Pollution Research Conference, 1970.

8. Pailthorp, R.E., Richter, G.A. and Filbert, J.S., "Anaerobic Secondary Treatment of Potato Process Wastewater," presented at the 44th WPCF Convention, San Francisco, October 1971.

9. Richter, G.A. and Mackie, J.A., "Low Cost Treatment for High Strength Waste," CH_2M Hill Rpt., October 1971.

10. Hovious, J.C., Fisher, J.A. and Conway, R.A., "Anaerobic Treatment of Synthetic Organic Wastes," EPA Report, Project 12020 DIS, January 1972.

11. Foree, E.G. and Lovan, C.R., "The Anaerobic Filter for the Treatment of Brewery Press Liquor Waste," Technical Report, IKY 46-72-CE12, April 1972.

12. Foree, E.G. and Horsley, E.E., "Advanced Studies of the Submerged Anaerobic Filter for Brewery Press Liquor Stabilization," Technical Report IKY 48-72CE 14, University of Kentucky, May 1972.

13. Tadman, J.M., Dow Chemical, Personal Communication, June 1973.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.) (4-76)

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE

REFERENCES (continued)

14. Campbell, G.R., Hydroscience, Personal Communication, 1973.

15. El Shafie, A.T. and Bloodgood, D.E., "Anaerobic Treatment in a Multiple Upflow System," JWPCF, 45, 2345-2357, 1973.

16. Dennis, N.D. and Jennett, C.S., "Pharmaceutical Waste Treatment with an Anaerobic Filter," 29th PIWC, May 1974.

17. Richter, G.A., Pailthorp, R.E. and Sirrine, K.L., "Aerobic Secondary Treatment of Potato Processing Wastes." 26th PIWC, 684-701, 1971.

18. Richter, G.A. and Mackie, J.A., "Waste Treatment System Removals 75-80% COD," Food Processing, June 1972.

19. Taylor, D.W., "Full Scale Anaerobic Trickling Filter Evaluation," Proceedings, 3rd National Symposium on Food Processing Wastes, EPA Report R 2-72-018, November 1972.

20. Andrews, J.F. and Graef, S.P., "Dynamic Modeling and Simulation of the Anaerobic Digestion Process," in ACS Monograph 105, Anaerobic Biological Treatment Processes, 1971.

21. Andrews, J.F., "Dynamic Model of the Anaerobic Digestion Process," JASCE, SED, 95-116, 1969.

22. Dorstal, K.A., "Centennial Mills Starch-Gluten Plant, Spokane, Washington," Unpublished Report, EPA, Pacific Northwest Environmental Research Laboratory, Received October 1974.

23. Jennett, J.A., Dennis, N.D., Jr., "Anaerobic Filter Treatment of Pharmaceutical Waste," JWPCF, 47, 104-121, 1975.

24. Wilson, A.W. and Timpany, P.L., "Anaerobic Contact Filter for Treatment of Waste Sulphite Liquor," Presented at the 59th Annual Meeting of the Canadian Pulp and Paper Association, Montreal, Quebec, January 1973.

25. Mueller, J.A. and Mancini, J.L., "Anaerobic Filter Kinetics and Application," Presented at the 30th Annual Purdue Industrial Waste Conference, May 1975.

26. Haug, R.T., Raksit, S.K. and Wong, G.G., "Anaerobic Filter Treats Waste Activated Sludge," Water and Sewage Works, 40-43, February 1977.

BEGIN LAST LINE OF TEXT HERE
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-787 (Cont.) (4-76)

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE
6 1/2"
9 1/2"
BEGIN LAST LINE OF TEXT
3/8"
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

27. Boyle, J.D., and Fruenwald, D.D., "Recycle of Liquor from the Treatment of Sludge," Journal Water Pollution Control Federation, 47, 2482 (1975).